UNIVERSITY OF ILLINOIS BULLETIN

ISSUED WEEKLY

Vol. XVI DECEMBER 9, 1918 No. 15

Entered as second-class matter December 11, 1912, at the post office at Urbana, Illinois, under the Act of August 24, 1912. Acceptance for mailing at the special rate of postage provided for in section 1103, Act of October 3, 1917, authorized July 31, 1918.]

PASSENGER TRAIN RESISTANCE

BY

EDWARD C. SCHMIDT

AND

HAROLD H. DUNN

BULLETIN No. 110

ENGINEERING EXPERIMENT STATION

PUBLISHED BY THE UNIVERSITY OF ILLINOIS, URBANA

PRICE: TWENTY CENTS

EUROPEAN AGENT

CHAPMAN & HALL, LTD., LONDON

THE Engineering Experiment Station was established by act of the Board of Trustees, December 8, 1903. It is the purpose of the Station to carry on investigations along various lines of engineering and to study problems of importance to professional engineers and to the manufacturing, railway, mining, constructional, and industrial interests of the State.

The control of the Engineering Experiment Station is vested in the heads of the several departments of the College of Engineering. These constitute the Station Staff and, with the Director, determine the character of the investigations to be undertaken. The work is carried on under the supervision of the Staff, sometimes by research fellows as graduate work, sometimes by members of the instructional staff of the College of Engineering, but more frequently by investigators belonging to the Station corps.

The results of these investigations are published in the form of bulletins, which record mostly the experiments of the Station's own staff of investigators. There will also be issued from time to time, in the form of circulars, compilations giving the results of the experiments of engineers, industrial works, technical institutions, and governmental testing departments.

The volume and number at the top of the front cover page are merely arbitrary numbers and refer to the general publications of the University of Illinois: *either above the title or below the seal is given the number of the Engineering Experiment Station bulletin or circular which should be used in referring to these publications.*

For copies of bulletins, circulars, or other information address the

ENGINEERING EXPERIMENT STATION,

URBANA, ILLINOIS.

UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

BULLETIN No. 110 DECEMBER, 1918

PASSENGER TRAIN RESISTANCE

BY

EDWARD C. SCHMIDT
PROFESSOR OF RAILWAY ENGINEERING

AND

HAROLD H. DUNN
RESEARCH ASSOCIATE IN RAILWAY ENGINEERING

ENGINEERING EXPERIMENT STATION
PUBLISHED BY THE UNIVERSITY OF ILLINOIS, URBANA

CONTENTS

LIST OF FIGURES

LIST OF TABLES

PASSENGER TRAIN RESISTANCE

I. Introduction

1. *Preliminary Statement.*—The Department of Railway Engineering of the University of Illinois has for some years carried on experiments to determine the tractive resistance of steam railway trains and electric railway motor cars.* The results relating to steam railways thus far published have applied only to freight trains. This bulletin presents for the first time the results of the experiments with passenger trains. These experiments were begun in 1908 on light local trains and were resumed during the spring and summer of 1916 on heavy equipment in through passenger service.

The results here presented define the resistance of the trains tested throughout the ordinary range of speed of passenger trains. The fact is also made clear that in passenger as in freight trains the resistance expressed in pounds per ton varies with the average weight of the cars composing the train, being less for trains made up of heavy cars than it is for trains of light cars. As regards freight train resistance, this influence of car weight has been recognized for some years, and this recognition found application in freight service in the making of tonnage ratings even before complete experimental data were at hand. Today tonnage ratings almost universally embody distinctions based upon this influence of car weight.

It has always seemed likely that the specific resistance of passenger trains was similarly affected by the weight of the cars in the train. Notwithstanding this probability, however, the influence of car weight has frequently been ignored in dealing with problems in passenger train resistance. It is embodied in only a few of the formulas currently used for that purpose, and even in some of these its influence is recognized only to the extent to which it affects the air

*See Bulletin 43, entitled "Freight Train Resistance: Its Relation to Car Weight," 1910, Bulletin 59, entitled "The Effects of Cold Weather upon Train Resistance and Tonnage Rating," 1912, Bulletin 74, entitled "The Tractive Resistance of a 28-ton Electric Car," 1914, and Bulletin 92, entitled "The Tractive Resistance on Curves of a 28-ton Electric Car," 1916, of the Engineering Experiment Station of the University of Illinois.

resistance component of net resistance, its effect on journal and rolling resistance being neglected. This situation has arisen primarily because of the lack of experimental data applying to passenger cars of different weights, and because the problems requiring the prediction of passenger train resistance have not the economic importance of similar problems arising in connection with freight trains. The error involved by ignoring car weight is not, however, so great in the former case as in the latter; for while passenger cars ordinarily vary in gross weight only from about thirty-five to sixty-five tons, the corresponding range in freight service is from about eighteen to ninety-eight tons. Despite this difference in the necessity of accurately determining resistance in the two instances, the prediction of passenger train resistance is nevertheless important, and data such as are here presented have been needed.

The results here set forth define the resistance of passenger trains made up of cars ranging in average weight from thirty-three to seventy-one tons, and, it is believed, present for the first time full experimental data showing the influence of car weight on the resistance of entire steam railroad passenger trains throughout the range of car weight now prevalent in American practice.* Throughout this bulletin the terms ''resistance,'' ''net resistance,'' and ''specific resistance'' mean the number of pounds of tractive force required for each ton of train weight in order to keep the train moving at uniform speed on straight level track. Ordinarily these terms apply to resistance in still air. Here, however, they include the effects on resistance of such winds as prevailed during the tests, which, as later appears, were from various directions and of velocities as high as thirty-one miles per hour. The bulletin deals exclusively with the resistance of the cars alone—locomotive and tender resistance were not measured and are not discussed.

The results of the last eighteen tests included in this report were separately summarized and discussed in a paper on ''Passenger Train Resistance'' published in February, 1917 in Bulletin 194 of the American Railway Engineering Association.

2. *Acknowledgments.*—Through the courtesy of W. L. Park, Vice President, and R. W. Bell, General Superintendent of Motive

*Data concerning the resistance of two trains composed of cars of two different weights (46.2 tons and 62.7 tons) are given in Bulletin No. 26 of the Pennsylvania Railroad Company Test Department.

Power of the Illinois Central Railroad, the tests were made on the lines of that company between Champaign and Centralia, Illinois, and by means of a dynamometer car which since 1900 has been jointly owned by the Railroad Company and the University. The interest and the coöperation of E. H. Baker, Trainmaster at Champaign, under whose immediate direction the test car was handled, are also gratefully acknowledged.

II. Summary

At the expense of some duplication of statement, the following summary is presented at this point in order to provide a general view of the work.

3. *The Trains.*—The tests were undertaken to measure the resistance of passenger trains at all speeds up to seventy miles per hour and for average car weights varying throughout the entire current range in weight. The chief characteristics of the twenty-eight trains tested were as follows:

	Minimum	Maximum
Total weight (excluding locomotive and tender), tons	138	727
Number of cars in the train	4	12
Average gross weight per car, tons	33.6	71.1

Nine of these trains were in "local" service, the others in "through" service. Of the 240 cars composing these twenty-eight trains, 178 had six-wheel trucks, and 62 had four-wheel trucks.

4. *The Track.*—The experiments were made upon well constructed and well maintained main line track, nearly all of which is laid with either 85-pound or 90-pound rail. Except through station grounds where screenings or cinders are used for ballast, the track is ballasted with broken stone.

5. *The Results.*—The average values of the resistance of the trains tested are defined by the curves of Fig. 9. From these curves has been prepared Table 3, which shows probable average values of resistance for passenger trains composed of cars varying in weight from thirty to seventy-five tons, and at speeds ranging from five to seventy-five miles per hour. Individual trains will occasionally be met with whose general average resistance will exceed the values previously defined by from 8 to 10 per cent.

The tests were made in fair and moderate or warm weather during which the maximum wind velocity encountered at any time was, with one exception, twenty-five miles per hour. The results are probably safely applicable to passenger trains running under like conditions of track and weather. They should not, however, be applied without modification to trains running under widely different conditions.

III. The Trains, The Track and The Test Car

6. *The Trains Tested.*—The twenty-eight passenger trains included in the report were tested in two series. Series I comprises ten tests which were made in 1908-1909 in conjunction with freight resistance tests then in progress. At that time the test car was operated from Champaign to Mattoon, Illinois, in freight service and it was usually returned in local passenger train No. 24 from Mattoon to Champaign. The test car was operated upon one occasion at this period in through train No. 5, and Series I includes, therefore, nine runs with train 24 and one with train 5. The average weight of the cars in train 24 varied during the nine tests then made only from 33.6 to 40.7 tons, and the results based on this limited range in weight did not warrant generalizations. The opportunity to continue the tests with heavy trains did not present itself until May of 1916 when the work was resumed and continued during the summer with trains No. 5 and No. 2. Eleven tests were then made with train No. 5, "Fast Mail," running from Champaign to Centralia, and seven tests with train No. 2, "Through Mail," running from Centralia to Champaign. These eighteen tests constitute Series 2.

Considering both series together the range in train weight was from 138 to 727 tons, in average car weight from 33.6 to 71.1 tons, and the number of cars per train varied from 4 to 12. For each of the three classes of trains the variations in train weight, car weight, number of cars, and truck construction were as follows:

Train No.	Number of Trains Tested	Gross Weight of Train, Tons		Average Weight per Car, Tons		Number of Cars in the Train		Number of Cars per Train Having 4-wheel Trucks	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
24	9	138.0	234.2	33.60	40.70	4	6	3	4
5	12	370.6	615.5	46.32	55.90	10	12	2	3
2	7	549.0	727.0	63.49	71.10	8	11	0	2

Similar data and other details concerning the make-up of each of the trains are presented in Table 1.

Train No. 24 is scheduled to cover the 45 miles from Mattoon to Champaign in 1 hour and 22 minutes, a schedule speed of 32.9 miles per hour. A typical running time for this train is 1 hour and 10 minutes, equivalent to a running speed of 38.6 miles per hour. Train No. 5 is allowed by the schedule 3 hours and 35 minutes to cover the 124.5 miles from Champaign to Centralia; thus its schedule speed is 34.8 miles per hour. Its running time is about 2 hours and 51 minutes, which corresponds to a running speed of 43.7 miles per hour. Train No. 2 is scheduled between Centralia and Champaign at 3 hours and 5 minutes, a schedule speed of 40.4 miles per hour. For this train a typical running time, 2 hours and 37 minutes, is equivalent to a running speed of 47.5 miles per hour.

In eight of the nine tests of train 24 the resistance of the dynamometer car itself is included in the records and its weight is included in the train weight. The weight of the test car, 29 tons, is however not greatly different from the average weight of the cars in this train and its inclusion has lowered only slightly the average car weight. The test car weight is likewise included in five of the tests with trains 2 and 5, and in these instances its relatively light weight has lowered appreciably the normal average car weight. In the remaining fourteen tests the dynamometer car was coupled with its measuring drawbar toward the rear of the train, and in these cases its own resistance is excluded from the test car records. Its weight is consequently excluded from the train weights and has not affected the normal average car weights.

The net weights of all cars were obtained from the records of the Illinois Central Railroad and the Pullman Company. To determine the car loads passengers were counted and allowed for at 140 pounds each; the weights of baggage and mail were estimated by personal inspection and count of the contents of each car; the weight of express was determined by reference to the bills, supplemented by inspection and estimate. The error entailed by these methods certainly does not exceed fifteen per cent of the weight of the load, and since among all the trains the maximum load amounted to only 6.6 per cent of the gross train weight, the maximum error in gross train weight itself caused by inaccuracies in the processes described is less than one per cent.

Of the three classes of trains tested, local train No. 24 had the lowest average car weight and, naturally, the highest proportion of

four-wheel truck cars. Of the 45 cars composing these nine local trains, 28 (or 62 per cent) had four-wheel trucks. In the twelve trains No. 5 there were included altogether 129 cars, of which 27 (or 21 per cent) were equipped with four-wheel trucks. Train No. 2 had the heaviest cars and the smallest proportion of four-wheel truck cars. The seven trains of this class included 66 cars, of which only 7 (or 10.6 per cent) had four-wheel trucks. All other cars in the three classes of trains had six-wheel trucks.

Since car weight affects the specific resistance, not only through its influence on air resistance, but through its influence on journal and rolling resistance as well, there is apparently an inconsistency in method in grouping—as is done in this report—trains including both four-wheel and six-wheel truck cars, and especially in thus grouping trains which have in their make-up different proportions of the two kinds of trucks. This apparent inconsistency, considering the purpose of the investigation, is not so objectionable as may appear. It was not possible under the conditions under which the tests were made to control the make-up of the trains. The tests had to be made in regular service and the trains had to be accepted with their usual make-up. This limitation has not defeated the main purpose of the tests, for they were undertaken, not to distinguish the resistance of four-wheel and six-wheel truck cars, but to measure the resistance of ordinary passenger trains of widely different average car weight; and wide variation in car weight carries with it, in American practice, a variation in truck construction similar to that encountered in the trains here discussed. Any train of 35 to 40 tons average car weight is sure to include in its make-up four-wheel truck cars,—and in about the proportion which prevailed in these tests. Even the heaviest through trains are likely occasionally to include a car or two with four-wheel trucks, as was the case with Train No. 2.

7. *The Track.*—The track, formerly part of one of the oldest single-track lines in the State, was converted about twenty years ago into a double-track road. The roadbed is in good condition and the drainage in general is excellent. The track was especially surveyed for the purposes of these tests.

Except on a few short stretches through station grounds, where cinders and screenings are used for ballast, both tracks are ballasted with broken limestone. The cross-ties, 6 inches by 8 inches by 8 feet,

are spaced about 20 inches between centers and are of treated red oak, treated soft wood or untreated white oak. Seventy miles of the southbound track are laid with 90-pound rail of American Railway Association section, while the remaining 54.5 miles are laid with 85-pound rail of American Society of Civil Engineers section; 98.6 miles of the northbound track are laid with 85-pound rail of American Society of Civil Engineers section, while the remaining 25.9 miles are laid with 90-pound rail of American Railway Association section. All rails are laid with broken joints supported on two ties. During eight months of the year there is employed in maintaining this portion of the road a force of men averaging one man per mile of track. During the remaining four months this force is reduced to one man for each two miles.

8. *The Test Car.*—The dynamometer car used in these experiments has been described in detail in Bulletin 43 of the Engineering Experiment Station of the University of Illinois and in the *Railway Age Gazette* for February 19, 1909. The recording apparatus within the car produces continuous graphical records of the gross resistance of the train, speed, time, brake cylinder pressure, wind direction, wind velocity, and location of mile posts and other reference points. A reproduction of one of the test car records is given in Bulletin 43 previously mentioned. When supplemented by an accurate profile and train data, these records permit the calculation of train resistance at any point or section on the road. The methods by which these calculations were made and the precautions observed to ensure accuracy are explained later.

IV. Test Conditions, Methods and Calculations

9. *Test Conditions.*—In Table 1 are set forth for each test the weather conditions, the average velocity and the direction of the wind, and the air temperatures prevailing at the beginning and at the end of the test. With only two exceptions the tests were made on fair days and in moderate or warm weather. The average air temperature varied from 40 degrees F. during one test to 93 degrees F. in another. The average wind velocity was 20 m. p. h. or less during all but three tests. During two tests the average wind velocity was 25 m. p. h. and on only one it was 31 m. p. h.

While the wind velocity was recorded for each test, the uncertainties regarding its influence have made a definite evaluation of its share of the total resistance impracticable. It has seemed necessary, therefore, to regard the wind velocity as one of the incidental variables which is likely to be met with in train operation and which should be included in the final resistance values. It has, accordingly, been included and the terms "resistance" and "specific resistance" as here used include the resistance due to such winds as prevailed during the tests.

10. *Test Methods.*—As has already been stated the tests were run in regular service, no attempt being made to modify schedules or to control speed. During each test the data cited in the description of the test car were produced and from them resistance was calculated for as great a variety of speeds as the records presented. These resistance values were then plotted in a diagram such as any one of the curves in Fig. 1, which shows for the train in question the relation between resistance and speed. The production of such a diagram was the immediate purpose of each test, and it was the expectation that when the resistance-speed curves of the individual tests were brought together, analysis of the curves would reveal the relations existing between train resistance and car weight.

The pressure in the brake cylinder was recorded merely to make it possible to distinguish the periods when the brakes were applied, it being obviously necessary to avoid such portions of the record when

Table 1

Train Data and Weather Conditions

Test Number	Date of Test	Weather	Air Temperature Degrees F. At Beginning of Test	Air Temperature Degrees F. At End of Test	Approximate Average Wind Velocity — Miles per Hour	Range of Direction of the Wind with Respect to the Track[1] From	Range of Direction of the Wind with Respect to the Track[1] To	Train Length — Feet	Weights: Gross Train Weight — Tons	Weights: Average Gross Weight per Car — Tons	Total Number of Cars in the Train	No. of Cars Having 2 Axles per Truck	No. of Cars Having 3 Axles per Truck	Kind of Cars: Test	Kind of Cars: Baggage and Express	Kind of Cars: Mail	Kind of Cars: Coach	Kind of Cars: Pullman	Kind of Cars: Diner	Kind of Cars: Special
1	10-31-08	Fair	60	60	11	+20° R	—81° R	300	202.9	40.58	5	3	2	1	1	1	2	...	...	...
2	11- 7-08	"	50	55	13	+45° L	—88° L	300	203.5	40.70	5	3	2	1	1	1	2	...	...	...
3	11-21-08	"	62	60	8	+ 8° R	+39° R	300	185.1	37.02	5	3	2	1	1	1	2	...	...	...
4	1-23-09	"	66	70	20	+16° R	+39° R	345	234.2	39.03	6	3	3	1	2	1	2	...	...	...
5	1-28-09	Rainy	40	41	18	+28° R	+55° R	300	189.4	37.90	5	3	2	1	1	1	2	...	...	...
6	2- 2-09	Fair	45	45	11	+ C°	+33° L	300	185.5	37.10	5	3	2	1	1	1	2	...	...	...
7	3-12-09	Cloudy	41	41	11	+27° R	+60° R	300	185.6	37.12	5	3	2	1	1	1	2	...	...	...
8	3-27-09	Fair	40	45	13	+34° L	+68° L	330	168.0	33.60	5	4	1	1	1	1	2	...	...	...
9	4-17-09	"	74	71	31	+36° R	+59° R	255	138.0	34.50	4	3	1	...	1	1	2	...	...	...
10	7- 8-08	"	50	60	14	+10° L	+22° L	480	370.6	46.32	8	2	6	...	2	3	2	1	...	...
11	5-25-16	"	82	86	..	....	....	700	604.5	54.96	11	2	9	...	6	2	2	1	...	...
12	5-25-16	"	86	90	..	....	....	700	570.0	51.80	11	2	9	...	6	2	2	1	...	...
13	6- 9-16	"	72	72	20	—30° R	+55° R	700	615.5	55.90	11	2	9	...	4	4	2	1	...	...
14	6- 9-16	"	72	71	15	—40° R	+25° R	700	551.3	55.13	10	2	8	...	3	4	2	1	...	...
15	6- 9-16	"	72	69	10	—15° R	+10° R	640	727.0	66.10	11	1	10	1	1	1	3	4	1	...
16	6-22-16	"	75	77	..	....	....	660	538.5	49.04	11	2	9	...	5	2	2	1	...	1
17	6-22-16	"	77	80	..	....	....	660	562.0	51.18	11	3	8	...	6	2	2	1	...	...
18	6-22-16	"	83	82	20	—70° L	+25° R	520	588.2	65.29	9	1	8	1	1	1	2	3	1	...
19	6-22-16	"	82	81	20	—70° R	+15° R	580	634.9	63.49	10	2	8	1	1	1	3	3	1	...
20	7- 6-16	"	88	90	25	+ 0°	+20° L	650	601.6	50.13	12	3	9	1	6	2	2	1	...	...
21	7- 6-16	"	90	92	25	+ 0°	+10° L	580	535.2	48.65	11	3	8	1	5	2	2	1	...	...
22	7- 6-16	"	92	91	20	+15° L	+65° R	690	618.0	68.66	9	1	8	...	1	1	3	3	1	...
23	7- 6-16	"	91	90	20	+ 0°	+35° R	630	549.0	68.63	8	1	7	...	1	1	2	3	1	...
24	7-13-16	"	86	89	20	+15° L	+40° R	615	570.1	51.83	11	2	9	...	6	2	2	1	...	...
25	7-13-16	"	89	93	15	+ 5° R	+40° R	630	540.0	49.10	11	2	9	...	5	2	2	1	...	1
26	7-13-16	"	93	92	15	+30° L	+35° R	765	708.3	70.83	10	1	9	...	1	1	3	4	1	...
27	7-13-16	"	92	90	15	—60° R	+23° L	720	639.9	71.10	9	..	9	...	1	1	2	4	1	...
28	8- 2-16	"	72	72	20	+25° L	+45° L	675	606.2	55.10	11	2	9	...	6	2	2	1	...	...

[1]Direction is designated by the angle made with the track. A wind which has any component of its velocity helping the train forward is marked +; winds with opposing velocity components are marked —. Winds from the right side of the track are designated as R; from the left side as L; thus +40°R means a wind blowing from the rear and from the right hand side, whose direction makes an angle of 40 degrees with the track.

choosing sections for calculation. The wind velocity and direction relative to the test car were obtained by means of an anemometer and windvane mounted on its roof. When compounded with the known speed and direction of motion of the car, these data permit the determination of the actual wind direction and wind velocity with respect to the track. The location of the test car upon the road was defined by marking upon the chart the position of mile posts and stations at the moment they were passed by the car. This record makes it possible to correlate any portion of the chart with the road profile. In addition to the weight of the train there were recorded its length, the car names and numbers, and facts concerning the truck construction.

11. *Methods Employed in Calculating the Results.*—To produce for each train the resistance-speed curve referred to in the preceding section involves calculating the train resistance at various positions of the train upon the track, and the first step towards this end is the inspection of the test car record in order to select suitable points or sections at which the resistance may be calculated. The considerations of most importance in this selection are that the points represent finally as great a speed range as possible and that the speeds be approximately evenly distributed within this range. Points and sections were selected only where the entire train was running and continued to run upon straight track; resistance due to track curvature is therefore entirely eliminated. The data essential to the process of calculation are the drawbar pull of the engine, the train speed and its acceleration, the tonnage, and the profile. The pull and the speed, as previously stated, are determined from continuous curves drawn on the test car chart. Two processes have been used, designated here as method 1 and method 2. By method 1, the momentary values of pull, speed, acceleration, and grade were determined for a particular position of the train upon the road; by method 2 the average values of these quantities were determined for the period during which the test car was passing over a definite section of the track.

Under method 1, the point on the road having been chosen, the pull and the speed were found by direct readings from the chart. This pull divided by the tonnage gives the gross train resistance at this speed, and this gross resistance was then corrected for both acceleration and grade resistances. The acceleration was determined by graphical methods from the speed curve, and the grade was found by cor-

relating the position of the train with the profile. The points were all selected so that at the moment under consideration the entire train was on a nearly uniform grade. Method 1 results in momentary values of train resistance at the points considered.

By method 2 the average value of train resistance was determined for the period during which the test car at the head of the train was passing a selected section of the track. This track section corresponds to a certain length on the test car record. The section was selected so that the speed of the car when entering was nearly equal to its speed at exit and moreover so that no considerable variations in speed occurred during transit over the section. These portions of the chart having been chosen, the average pull was next found by determining the average ordinate of the curve of drawbar pull, and the average speed was found by means of the section length and the time record. Gross resistance in pounds per ton was next derived by dividing this value of pull by the tonnage, and this gross resistance was accordingly corrected for the resistances due to acceleration and grade, as in method 1. In this case the average acceleration is found by consideration of the speeds at entrance to and exit from the section. In order to correct for grade, the elevation of the center of gravity of the train was determined for that position of the train at which the test car entered the section, and again for the position at which the car left the section. The difference between these elevations establishes the effective average grade, which either helps or opposes the locomotive while the train passes the section. These elevations of the center of gravity of the train may not be determined with sufficient accuracy unless the train at the moment is on a practically uniform grade. The section limits were therefore so chosen. Method 2 results in a value of *average* train resistance for the *average* speed at which the train passes the section under consideration. It would be rigidly correct if train resistance varied uniformly with speed, in other words, if the curve showing the relation of resistance to speed were a straight line. This, of course, is not the relation, and the process accordingly gives results which are slightly in error. As previously stated, however, the section was chosen so that the difference between the speeds at entrance to and exit from the section was small, and for the speed range represented by this difference, the curve of train resistance deviates but little from a straight line. Such error as does result from the process is, therefore, very small, and is of no moment whatever when compared with

variations, due to natural causes, which occur in the resistance itself.

The two methods are fundamentally alike. Although the first is the less laborious, it requires the determination of acceleration at a point on the speed curve, which is occasionally difficult to make accurately. Method 2 is, accordingly, generally preferable, and it is also to be preferred because it deals with average values and therefore tends to eliminate from the results the incidental momentary variations which frequently occur in train resistance. Method 2 has consequently been used during these tests whenever it was possible to do so, but it has been necessary occasionally to resort to the use of method 1, especially for the determination of resistance at low speed, because in passenger service low speeds are rarely maintained for a long enough period to permit the use of the second method. Of all the resistance values included in this report only about 16 per cent were derived by method 1. These values are represented in the resistance speed diagrams by the circles, whereas values derived by method 2 are represented by the black dots.

In general the methods used during these tests were like those set forth in Bulletin 43 of the Engineering Experiment Station of the University of Illinois and described in detail in sections 11 to 15 and in Appendix 4 of that bulletin. The precautions taken to ensure accuracy which are there described, particularly in the determination of the acceleration corrections, were strictly observed in these experiments.

12. *The Derivation of the Resistance Curves.*—The calculations result, for each test, in a series of values of net train resistance at a variety of speeds. These values of resistance were plotted with respect to speed, and gave such a diagram as in Fig. 1. The curve, such as is shown there, was next drawn to express, for the test in question, the relation existing between resistance and speed. In order to draw this curve, the plotted points were assumed to be arranged in a number of groups, and for each group the averages of the values of speed and of resistance were determined. By these averages a new point or "center of gravity" of the group was then plotted. The curve was drawn by confining attention to the few points thus determined. The groups of points were arbitrarily selected so that the resulting "centers of gravity" would be distributed nearly equidistantly throughout the speed range. All curves presented in the report, except those shown in Fig. 9, were drawn by this process.

V. The Results of the Tests

13. *Results of the Individual Tests.*—The immediate result of each test is a curve which shows for the train under consideration the relation existing between train resistance and speed. Fig. 1 includes such a curve for the train of test 1, in which the average weight of the cars was 40.58 tons. Similar curves for each of the twenty-eight trains tested are presented in Figs. 1 to 5 inclusive.

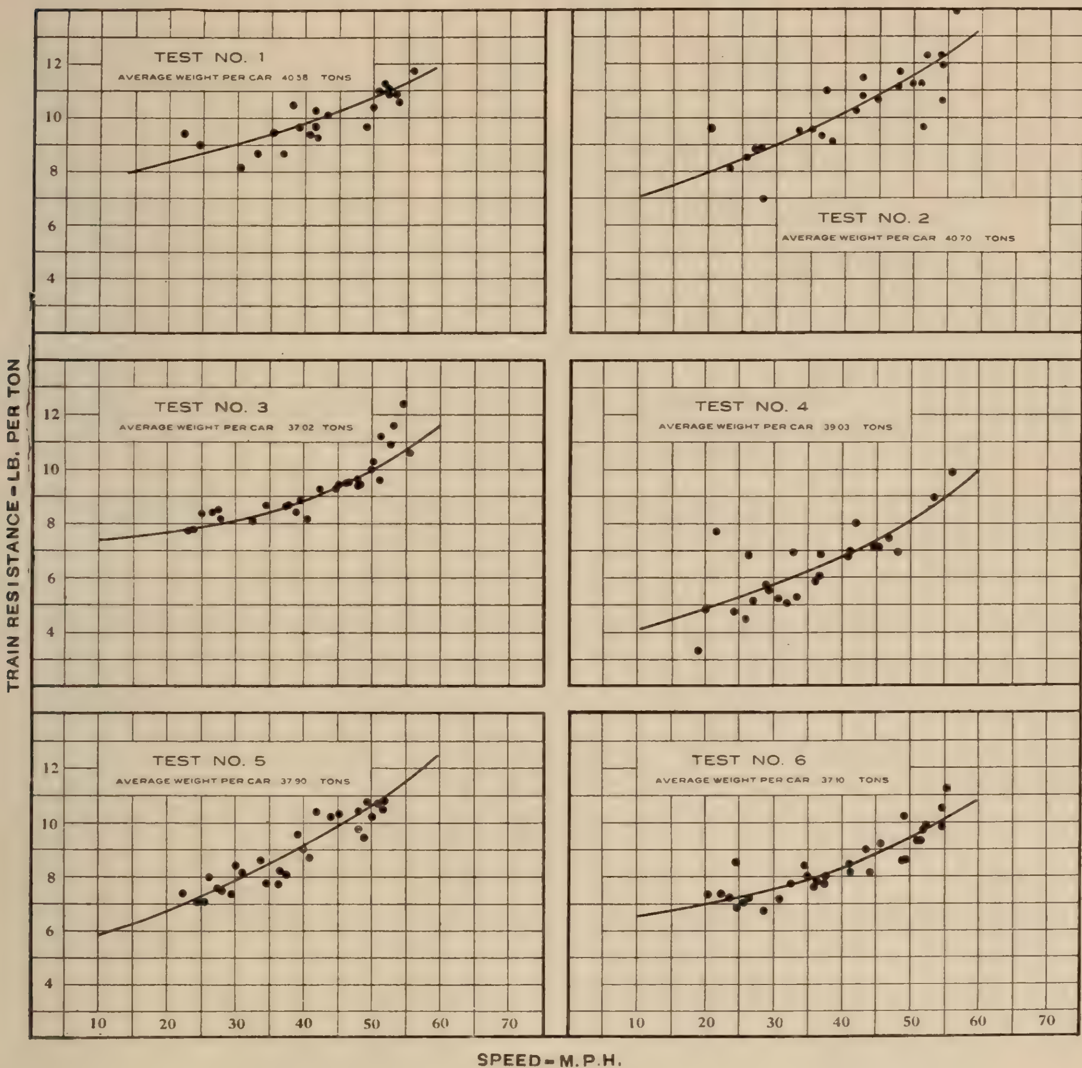

Fig. 1. Diagrams Showing the Relation between Train Resistance and Speed for Six Trains

There is considerable variation among the points on the individual plots of Figs. 1 to 5, as well as considerable variation of the points from the mean defined by the curves. It is possible that part of this variation may be due to accumulated errors in instruments or in the

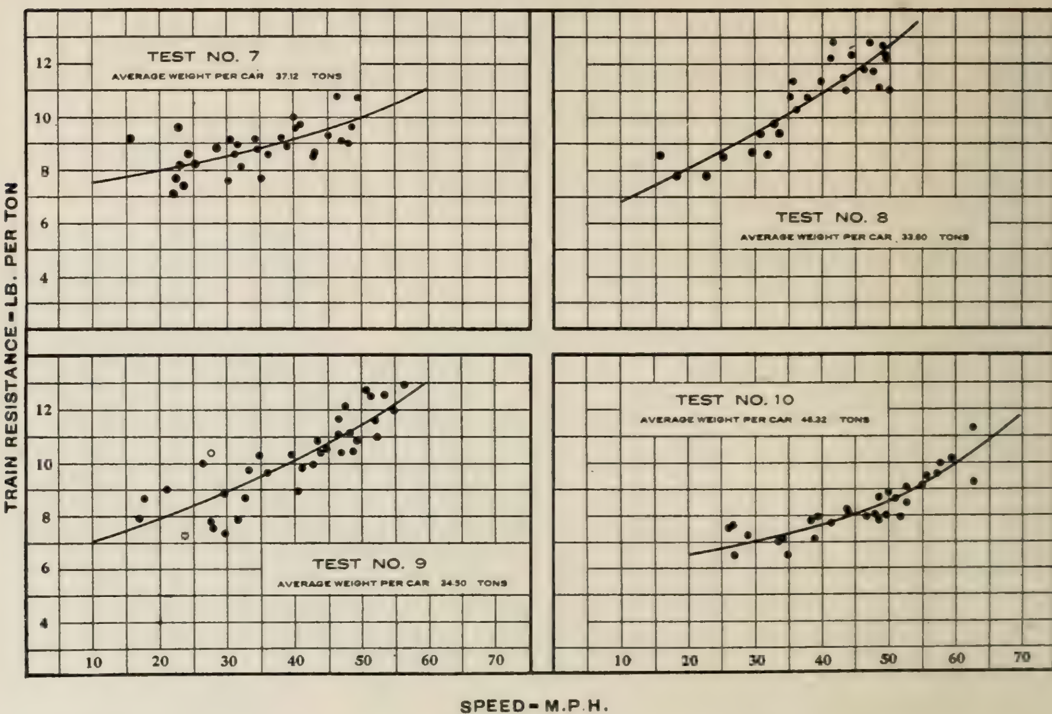

FIG. 2. DIAGRAMS SHOWING THE RELATION BETWEEN TRAIN RESISTANCE AND SPEED FOR FOUR TRAINS

calculations, but since every precaution was taken to avoid such errors, they are undoubtedly of little consequence. The data, particularly for certain tests during which wind conditions changed considerably, indicate that the usual variations in the direction and velocity of the wind during any test are sufficient to account for the differences in train resistance shown in these figures. Variations in such other components of train resistance as journal friction and oscillatory resistances are also undoubtedly accountable in a large degree for the differences discussed. The data do not afford a means of evaluating the influence of such components of resistance.

14. *Results of All the Tests.*—The twenty-eight curves from Figs. 1 to 5 have been brought together in Fig. 6 which embodies, therefore, the immediate results of all the tests. These curves make

it clear that there was a maximum variation of about 75 per cent in the resistance of different trains. Difference in wind velocity fails to account for this variation, except in a few selected cases, but there

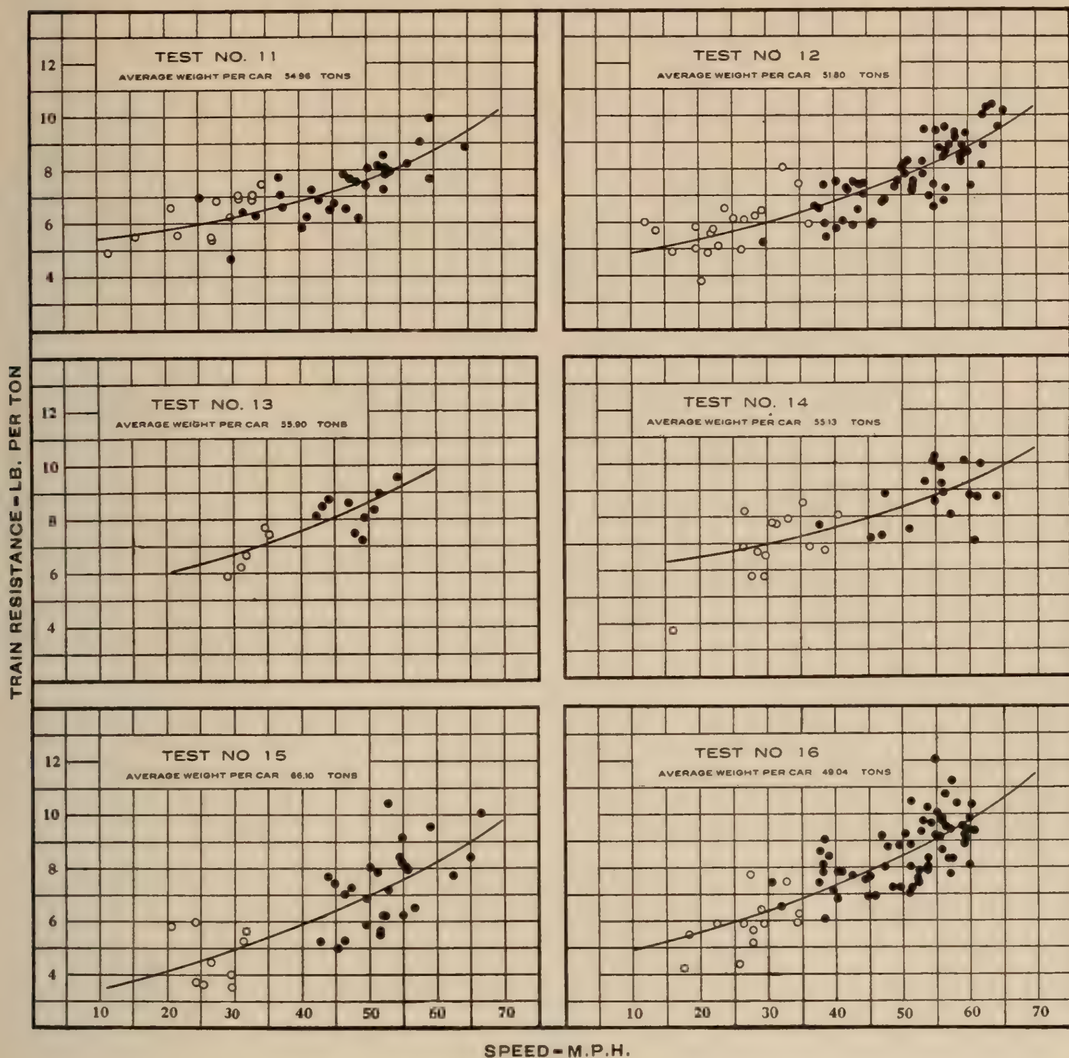

FIG. 3. DIAGRAMS SHOWING THE RELATION BETWEEN TRAIN RESISTANCE AND SPEED FOR SIX TRAINS

was every reason to believe that as in the freight train resistance tests reported in Bulletin 43 of the Engineering Experiment Station the divergence of these curves might be explained by the variation in the average weight of the cars going to make up the different trains. Comparison with the tabular data shows that the four upper curves are derived from tests of trains in which the average car weight was 36.5 tons while the four lower curves are from tests of trains in which the

average car weight was 69.8 tons. These facts serve as a rough indication of the part played by car weight in effecting changes in train resistance. As has been previously stated, this conclusion was anticipated when the work was begun and tests were made therefore with trains which cover the ordinary range of passenger car weight.

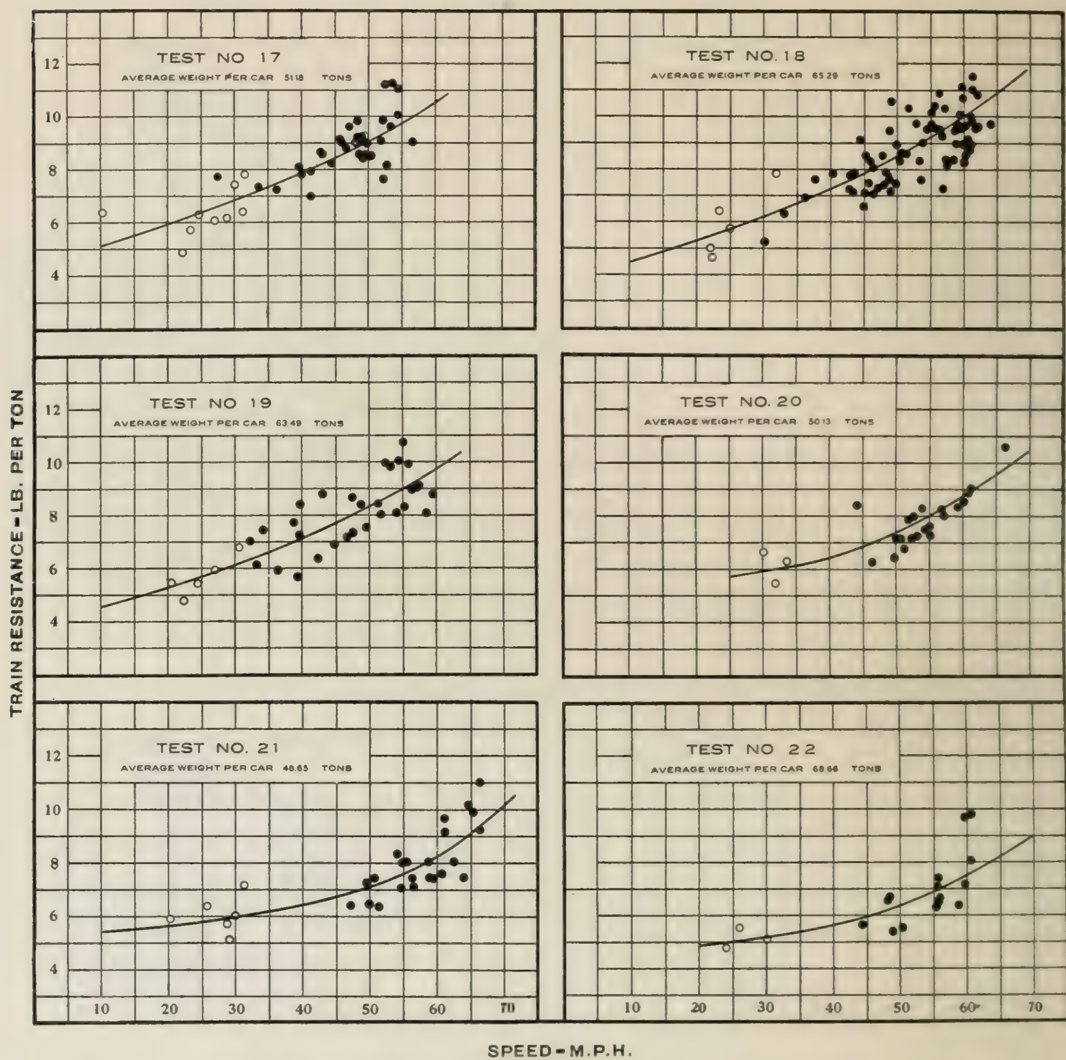

Fig. 4. Diagrams Showing the Relation between Train Resistance and Speed for Six Trains

If in Fig. 6 at the point corresponding to 20 miles per hour a perpendicular is erected, it will cut the curves in twenty-eight points, each of which pertains to a particular train and defines for that train the average value of resistance at a speed of 20 miles per hour. If each of these resistance values is plotted with respect to the average

car weight of the train to which it pertains, the diagram for 20 miles per hour shown in Fig. 7 is obtained. Since in this diagram the values of resistance all relate to a common speed, the influence of speed on resistance is eliminated, and the figure shows the relation which at 20 miles per hour exists between resistance and average car weight. Fig.

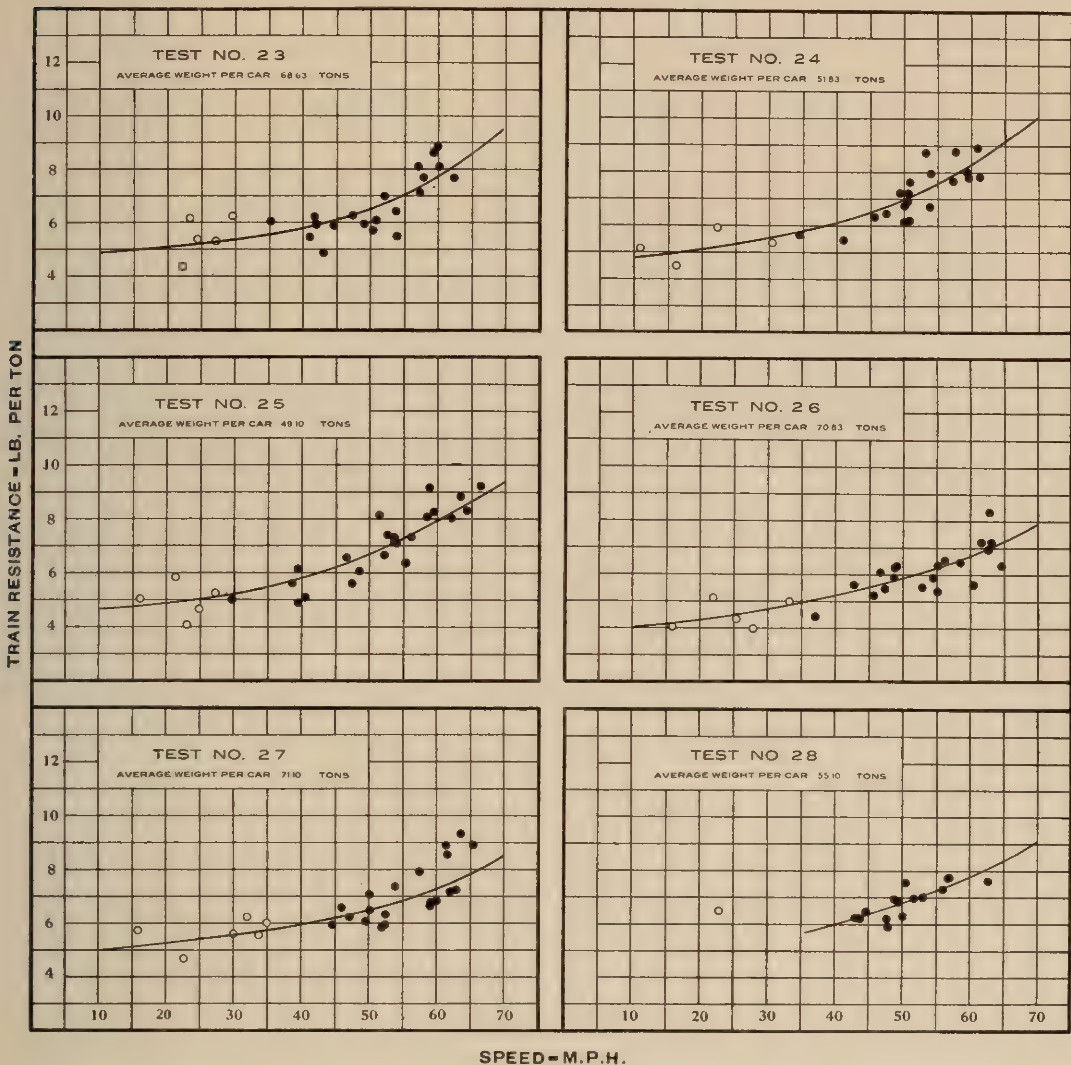

FIG. 5. DIAGRAMS SHOWING THE RELATION BETWEEN TRAIN RESISTANCE AND SPEED FOR SIX TRAINS

7 includes seven diagrams obtained by this process for speeds of 10, 20, 30, 40, 50, 60 and 70 miles per hour. The coördinates of the points plotted in Fig. 7 are given in Table 2. In it the tests are arranged in the order of the average car weights.

Both Fig. 7 and Table 2 show that the points on the individual plots fall into three groups. The group having the lowest average car weight was obtained from tests made on local train number 24 which has been described on page 12 and in Table 1. It has been noted that the number of cars in these trains having four-wheel trucks varied from 50 per cent to 80 per cent. The intermediate group of points was derived from tests with train number 5 in which the number of cars having four-wheel trucks varied from 18 per cent to 27 per cent. The group of points pertaining to trains having a high average car weight applies to tests made on train number 2 in which the number of cars having four-wheel trucks varied from 0 per cent to 20 per cent.

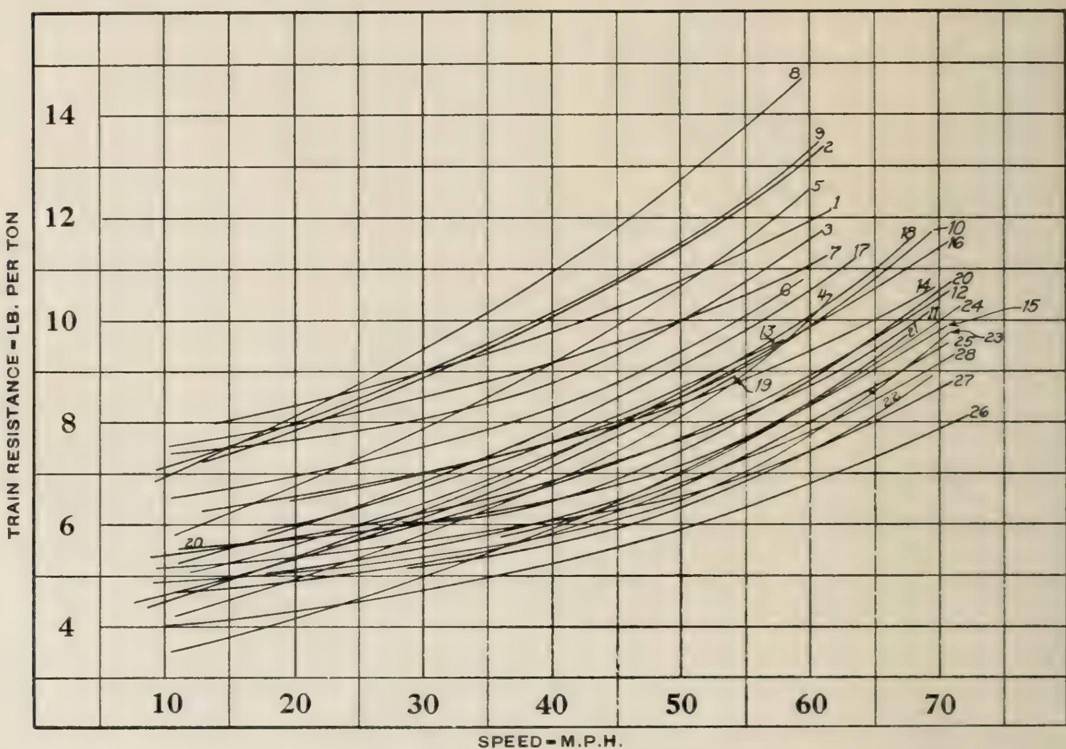

FIG. 6. CURVES SHOWING THE RELATION BETWEEN TRAIN RESISTANCE AND SPEED FOR THE TWENTY-EIGHT TRAINS TESTED

In considering the variation among the points on the individual plots of Fig. 7 it should be borne in mind that each point represents the average resistance of a particular train at a given speed. With the exception of test number 4 which results in abnormally low resistance values the average variation of all the points from the mean

curves is 8 per cent. There are three trains which at some speed gave resistances greater than 20 per cent above or below the mean curve. The majority, however, vary from the curve by 10 per cent or less.

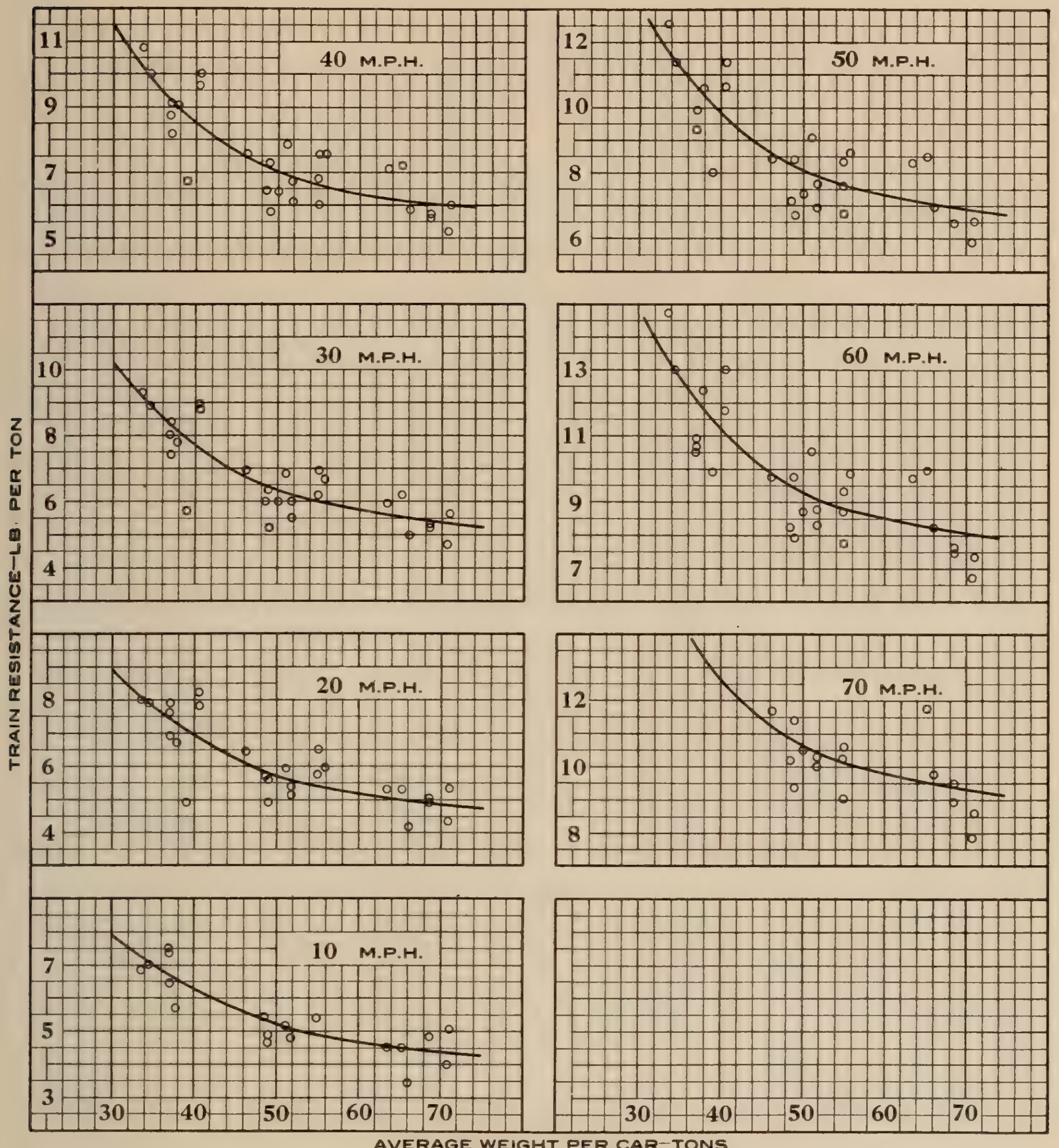

Fig. 7. Diagrams Showing the Relation between Train Resistance and Average Car Weight for Seven Different Speeds

In the following table are given the average deviations above and below the mean for all the points in Fig. 7.

No satisfactory explanation for these differences is obtainable from the data. They are probably due to varying external conditions

such as wind and temperature as well as to variations in train condition and make up. Variations similar to those recorded in the foregoing table may be expected with any train.

Table 2

Values of Resistance at Various Speeds Derived from the Curves for the Individual Tests

This table provides the coördinates of the points plotted in Fig. 7

Test No.	Average Weight per Car Tons	Train Resistance—Pounds per Ton						
		10 M. P. H.	20 M. P. H.	30 M. P. H.	40 M. P. H.	50 M. P. H.	60 M. P. H.	70 M. P. H.
8	33.60	6.83	8.00	9.30	10.80	12.56	14.72	......
9	34.50	7.01	7.90	8.90	10.00	11.39	13.00	......
3	37.02	7.35	7.61	8.03	8.73	9.91	10.50	......
6	37.10	6.45	6.90	7.43	8.18	9.30	10.67	......
7	37.12	7.47	7.90	8.42	9.10	9.91	10.92	......
5	37.90	5.70	6.70	7.80	9.05	10.58	12.38	......
4	39.03	......	4.90	5.72	6.73	8.00	9.90	......
1	40.58	......	8.23	8.89	9.65	10.60	11.78	......
2	40.70	......	7.81	8.80	10.00	11.35	13.00	......
10	46.32	......	6.42	6.93	7.57	8.42	9.76	11.68
21	48.65	5.44	5.70	6.00	6.45	7.14	8.23	10.20
16	49.04	4.90	5.60	6.35	7.30	8.40	9.73	11.40
25	49.10	4.67	4.89	5.21	5.80	6.70	7.91	9.38
20	50.13	......	......	6.00	6.40	7.35	8.70	10.50
17	51.18	5.18	5.92	6.82	7.85	9.08	10.52	......
12	51.80	4.85	5.38	6.00	6.72	7.65	8.78	10.30
24	51.83	4.80	5.12	5.51	6.10	6.93	8.30	10.00
11	54.96	5.40	5.75	6.20	6.81	7.60	8.70	10.25
28	55.10	......	......	......	6.00	6.76	7.76	9.05
14	55.13	......	6.50	6.95	7.55	8.33	9.31	10.60
13	55.90	......	5.96	6.68	7.56	8.60	9.85	......
19	63.49	4.52	5.30	5.94	7.10	8.30	9.70	......
1[illegible]	65.29	4.51	5.30	6.20	7.22	8.48	9.94	11.75
15	66.10	3.46	4.17	4.98	5.87	6.94	8.22	9.77
23	68.63	4.84	5.02	5.30	5.74	6.45	7.62	9.50
22	68.66	......	4.90	5.20	5.64	6.38	7.45	8.94
26	70.83	4.00	4.32	4.70	5.20	5.88	6.71	7.87
27	71.10	5.08	5.32	5.62	6.00	6.50	7.32	8.60

Although there is considerable variation among the points, they indicate clearly a decrease in the resistance as the car weight increases. The rate of this decrease is shown by the curves drawn to represent the points on the individual plots of Fig. 7. These curves have been drawn by the same method as the curves of Figs. 1 to 5 inclusive.

The seven curves from the individual plots of Fig. 7 have been brought together in Fig. 8, which shows, therefore, the average rela-

tion between resistance and average car weight for each of seven different speeds. Fig. 8 shows in graphical form the results of the whole research.

AVERAGE DEVIATION OF ALL POINTS IN FIG. 7 FROM THE MEAN AS SHOWN BY THE CURVES THERE DRAWN EXPRESSED AS PERCENTAGES OF THE CURVE ORDINATES

	Miles per Hour						
Speed	10	20	30	40	50	60	70
Points above the Curve	8.7	6.5	7.1	9.0	9.0	10.2	6.7
Points below the Curve	6.6	8.3	7.3	8.5	8.6	7.1	6.6

15. *The Results Expressed as Resistance-Speed Curves.*—Fig. 8, however, presents the relations in unusual form. Ordinarily train resistance is expressed as a curve or equation which defines the relation between resistance and speed instead of the relation between resistance and car weight as in this figure. Obviously a single curve will not suffice to express the results of these experiments in the usual form, since the influence of car weight cannot thereby be made evident. A number of curves will be required for this purpose, each of which will apply only to a particular average car weight. Fig. 9 presents such a group of resistance speed curves which have been derived directly from the lines of Fig. 8, and Fig. 9 shows, therefore, in different form, only such information as is obtainable from Fig. 8.

The relation between the two figures will be made clear by explaining the derivation of the curve in Fig. 9 applying to an average car weight of 40 tons. In Fig. 8 the ordinate corresponding to an average car weight of 40 tons cuts the seven lines there drawn at seven points, at which the mean resistance values are 6.3, 7.0, 7.7, 8.6, 9.8, 11.2, and 12.7 pounds per ton, corresponding to speeds of 10, 20, 30, 40, 50, 60 and 70 miles per hour respectively. These values are the coördinates of seven points on a resistance-speed curve applying to a car weight of 40 tons. These seven points have been plotted in Fig. 9 and define there the curve for 40 tons. The curves for 30, 35, 45, 50, 60, and 75 tons average weight per car have been derived in like manner. The curves of Fig. 9 reproduce quite exactly the facts presented in Fig. 8 and present the final results of the experiments. Three additional curves corresponding to 55, 65, and 70 tons per car which were included in the original diagram have been omitted from Fig. 9 to avoid confusion.

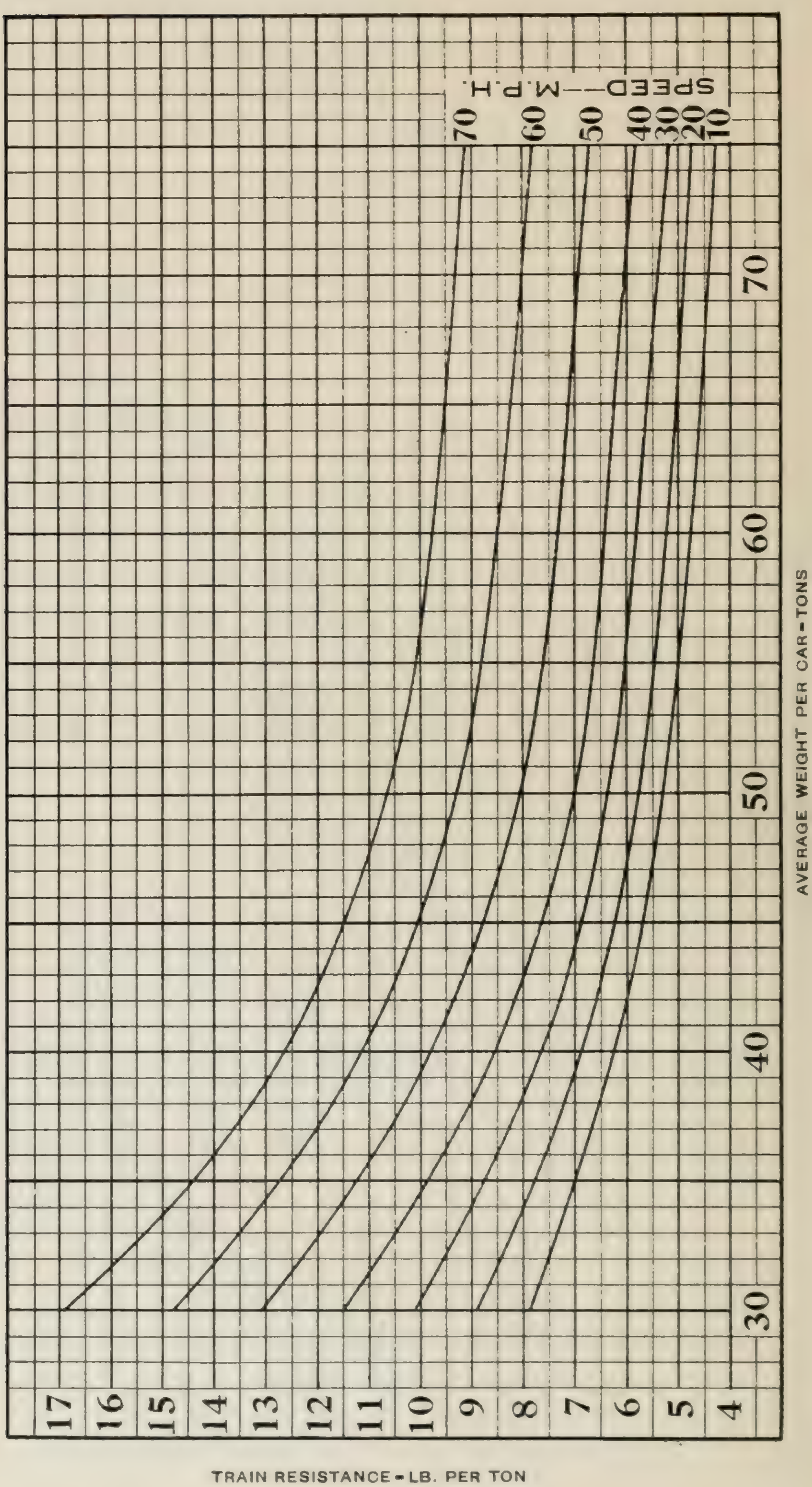

Fig. 8. Curves Showing the Average Relation between Resistance and Average Car Weight for Seven Different Speeds

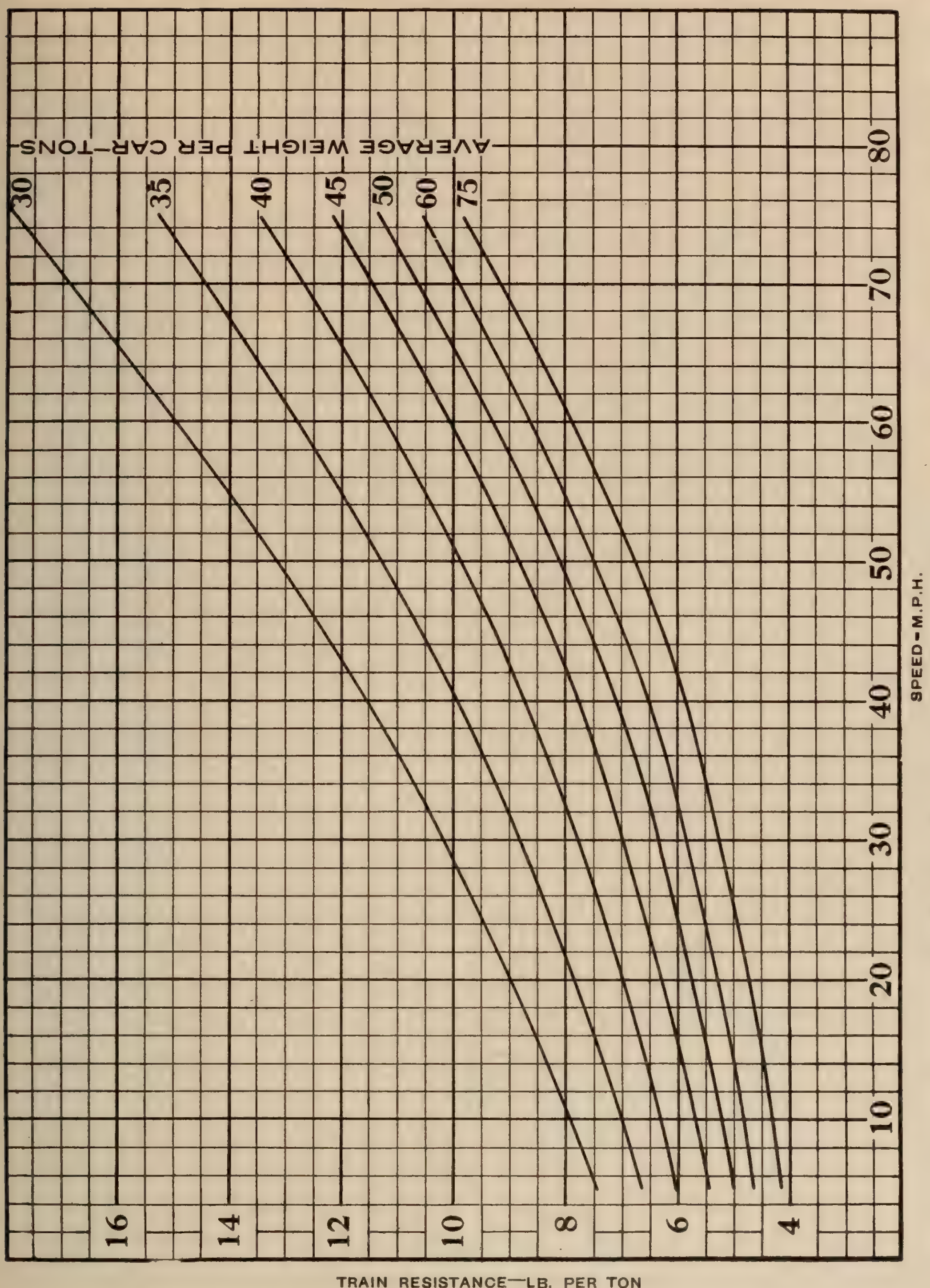

Fig. 9. Curves Showing the Relation between Train Resistance and Speed for Average Car Weight between Thirty and Seventy-five Tons

16. *The Results Expressed in Tabular Form.*—For convenience the values of resistance defined by the curves of Figs. 8 and 9 have been tabulated in Table 3 which gives the resistance values at speeds

Table 3

Values of Resistance at Various Speeds and for Various Average Car Weights

The values are derived directly from the curves of Fig. 9 and present the final results of the tests

Speed Miles per Hour	Train Resistance—Pounds per Ton										Speed Miles per Hour
	Column Headings Indicate the Average Weights per Car—Tons										
	30	35	40	45	50	55	60	65	70	75	
5	7.4	6.6	6.0	5.4	5.0	4.8	4.6	4.4	4.3	4.1	5
6	7.5	6.7	6.0	5.5	5.0	4.8	4.6	4.4	4.3	4.2	6
7	7.6	6.8	6.1	5.5	5.1	4.8	4.7	4.5	4.3	4.2	7
8	7.7	6.8	6.2	5.6	5.1	4.9	4.7	4.5	4.4	4.2	8
9	7.8	6.9	6.2	5.6	5.2	4.9	4.8	4.6	4.4	4.3	9
10	7.9	7.0	6.3	5.7	5.2	5.0	4.8	4.6	4.4	4.3	10
11	8.0	7.1	6.4	5.8	5.2	5.0	4.8	4.7	4.5	4.3	11
12	8.1	7.1	6.4	5.8	5.3	5.0	4.9	4.7	4.5	4.4	12
13	8.2	7.2	6.5	5.9	5.3	5.1	4.9	4.7	4.5	4.4	13
14	8.3	7.3	6.5	5.9	5.4	5.1	5.0	4.8	4.6	4.4	14
15	8.4	7.4	6.6	6.0	5.4	5.2	5.0	4.8	4.6	4.5	15
16	8.5	7.5	6.7	6.0	5.5	5.2	5.0	4.9	4.7	4.5	16
17	8.6	7.6	6.7	6.1	5.5	5.3	5.1	4.9	4.7	4.5	17
18	8.7	7.7	6.8	6.1	5.6	5.3	5.1	5.0	4.8	4.6	18
19	8.8	7.7	6.9	6.2	5.7	5.4	5.2	5.0	4.8	4.6	19
20	9.0	7.8	7.0	6.3	5.7	5.4	5.2	5.0	4.9	4.7	20
21	9.1	7.9	7.0	6.3	5.8	5.5	5.3	5.1	4.9	4.7	21
22	9.2	8.0	7.1	6.4	5.8	5.5	5.3	5.1	5.0	4.8	22
23	9.3	8.1	7.2	6.4	5.9	5.6	5.4	5.2	5.0	4.8	23
24	9.4	8.2	7.2	6.5	5.9	5.6	5.4	5.2	5.0	4.9	24
25	9.5	8.3	7.3	6.6	6.0	5.7	5.5	5.3	5.1	4.9	25
26	9.6	8.4	7.4	6.6	6.1	5.7	5.6	5.4	5.1	5.0	26
27	9.8	8.5	7.5	6.7	6.1	5.8	5.6	5.4	5.2	5.0	27
28	9.9	8.6	7.5	6.8	6.2	5.9	5.7	5.5	5.2	5.1	28
29	10.0	8.7	7.6	6.8	6.2	5.9	5.7	5.5	5.3	5.1	29
30	10.1	8.8	7.7	6.9	6.3	6.0	5.8	5.6	5.4	5.2	30
31	10.3	8.9	7.8	7.0	6.4	6.0	5.8	5.6	5.4	5.2	31
32	10.4	9.0	7.9	7.1	6.4	6.1	5.9	5.7	5.5	5.3	32
33	10.5	9.1	8.0	7.1	6.5	6.2	6.0	5.8	5.5	5.4	33
34	10.7	9.2	8.0	7.2	6.6	6.2	6.0	5.8	5.6	5.4	34
35	10.8	9.3	8.1	7.3	6.7	6.3	6.1	5.9	5.7	5.5	35
36	10.9	9.4	8.2	7.4	6.7	6.4	6.2	6.0	5.7	5.5	36
37	11.1	9.5	8.3	7.4	6.8	6.5	6.2	6.0	5.8	5.6	37
38	11.2	9.6	8.4	7.5	6.9	6.5	6.3	6.1	5.9	5.7	38
39	11.4	9.8	8.5	7.6	7.0	6.6	6.4	6.2	5.9	5.7	39
40	11.5	9.9	8.6	7.7	7.0	6.7	6.4	6.2	6.0	5.8	40
41	11.7	10.0	8.7	7.8	7.1	6.8	6.5	6.3	6.1	5.9	41
42	11.8	10.1	8.8	7.9	7.2	6.9	6.6	6.4	6.2	6.0	42
43	12.0	10.3	9.0	8.0	7.3	6.9	6.7	6.5	6.3	6.0	43
44	12.2	10.4	9.1	8.1	7.4	7.0	6.8	6.6	6.4	6.1	44
45	12.3	10.5	9.2	8.2	7.5	7.1	6.9	6.7	6.4	6.2	45
46	12.5	10.7	9.3	8.3	7.6	7.2	7.0	6.8	6.5	6.3	46
47	12.6	10.8	9.4	8.4	7.7	7.3	7.1	6.9	6.6	6.4	47
48	12.8	11.0	9.6	8.5	7.8	7.4	7.2	7.0	6.7	6.5	48
49	13.0	11.1	9.7	8.6	7.9	7.5	7.3	7.1	6.8	6.6	49
50	13.1	11.2	9.8	8.8	8.0	7.6	7.4	7.2	7.0	6.7	50
51	13.3	11.4	9.9	8.9	8.1	7.7	7.5	7.3	7.1	6.8	51
52	13.5	11.5	10.1	9.0	8.2	7.8	7.6	7.4	7.2	6.9	52
53	13.7	11.7	10.2	9.1	8.4	7.9	7.7	7.5	7.3	7.0	53
54	13.8	11.8	10.3	9.2	8.5	8.1	7.8	7.6	7.4	7.1	54
55	14.0	12.0	10.5	9.4	8.6	8.2	8.0	7.7	7.5	7.2	55

TABLE 3—(CONTINUED)

Speed Miles per Hour	Train Resistance—Pounds per Ton										Speed Miles per Hour
	Column Headings Indicate the Average Weights per Car—Tons										
	30	35	40	45	50	55	60	65	70	75	
56	14.2	12.1	10.6	9.5	8.7	8.3	8.1	7.8	7.6	7.3	56
57	14.4	12.3	10.8	9.6	8.9	8.4	8.2	8.0	7.7	7.5	57
58	14.6	12.5	10.9	9.8	9.0	8.6	8.3	8.1	7.8	7.6	58
59	14.8	12.6	11.1	9.9	9.1	8.7	8.4	8.2	8.0	7.7	59
60	15.0	12.8	11.2	10.0	9.2	8.8	8.6	8.3	8.1	7.8	60
61	15.1	12.9	11.3	10.2	9.4	8.9	8.7	8.4	8.2	7.9	61
62	15.3	13.1	11.5	10.3	9.5	9.1	8.8	8.6	8.3	8.1	62
63	15.5	13.2	11.7	10.5	9.7	9.2	9.0	8.7	8.5	8.2	63
64	15.7	13.4	11.8	10.6	9.8	9.3	9.1	8.8	8.6	8.3	64
65	15.9	13.6	11.9	10.7	9.9	9.5	9.2	8.9	8.7	8.4	65
66	16.1	13.8	12.1	10.9	10.0	9.6	9.3	9.1	8.8	8.6	66
67	16.3	13.9	12.2	11.0	10.2	9.7	9.4	9.2	9.0	8.7	67
68	16.5	14.1	12.4	11.1	10.3	9.9	9.6	9.3	9.1	8.8	68
69	16.7	14.3	12.5	11.3	10.5	10.0	9.7	9.5	9.2	9.0	69
70	16.9	14.4	12.7	11.4	10.6	10.1	9.9	9.6	9.4	9.1	70
71	17.1	14.6	12.8	11.6	10.7	10.3	10.0	9.7	9.5	9.2	71
72	17.3	14.8	13.0	11.7	10.9	10.4	10.1	9.9	9.6	9.4	72
73	17.5	15.0	13.1	11.9	11.0	10.6	10.3	10.0	9.8	9.5	73
74	17.7	15.1	13.3	12.0	11.2	10.7	10.4	10.1	9.9	9.7	74
75	17.9	15.3	13.5	12.1	11.3	10.8	10.5	10.3	10.0	9.8	75

between 5 and 75 miles per hour and for car weights ranging from 30 to 75 tons. Table 3 also includes the coördinates of the resistance curves corresponding to 55, 65 and 70 tons per car and omitted from Fig. 10.

17. *Final Results.*—The final results of the research are presented in the two forms just stated, namely, Fig. 9 and Table 3, from which the resistance of ordinary passenger trains may be predicted with reasonable accuracy. It should be borne in mind, however, that these results are applicable to trains running at uniform speed, on level tangent track of good construction, during weather when the temperature is not lower than 40 degrees F. and when the wind velocity does not exceed 25 m. p. h.*

It is also significant that a considerable number of the tests developed resistances averaging about 8 per cent in excess of the mean resistance which would be predicted by the use of Figs. 7, 8 or 9. It should be understood that this allowance is intended to cover probable variations in the resistance of different trains under normal op-

*Twenty-five of the tests here reported were made when the wind velcocity did not exceed 20 m. p. h. During two tests it did not exceed 25 m. p. h. and during only one test did it exceed 30 m. p. h.

erating conditions. This allowance in no way takes the place of that additional reserve which must be allowed to cover unusual variations in resistance due to low temperatures, or high winds or of that reserve in tractive effort of the locomotive necessitated by operating conditions which reduce the efficiency of the locomotive itself.

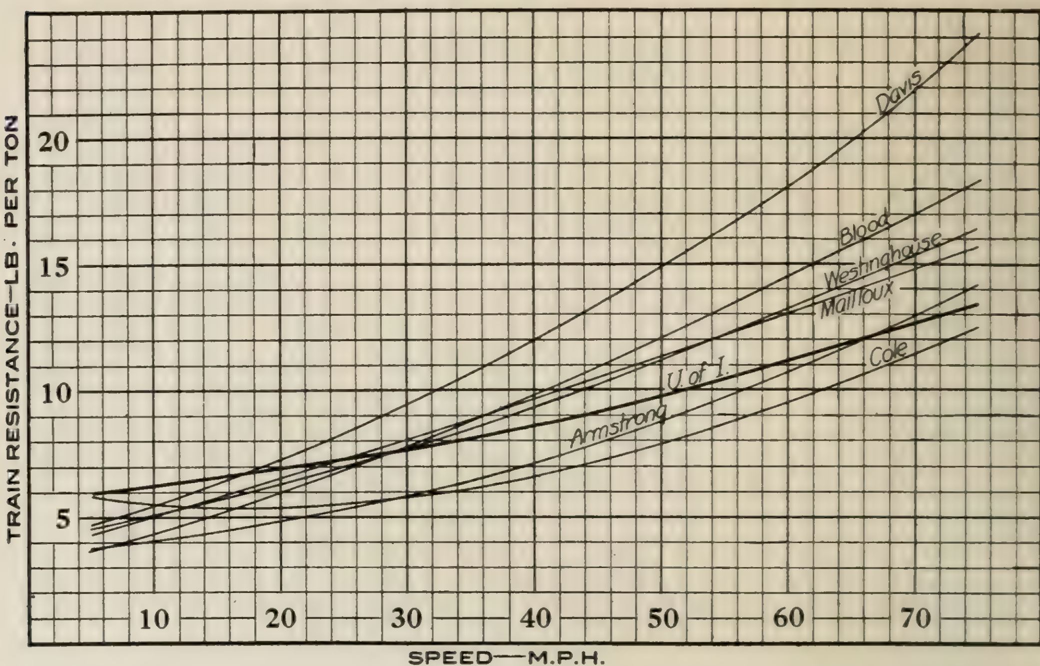

FIG. 10. COMPARATIVE CURVES SHOWING THE RELATION BETWEEN TRAIN RESISTANCE AND SPEED FOR TRAIN COMPOSED OF EIGHT 40-TON CARS

18. *Comparison with Other Experiments.*—For purposes of comparison with the results of other investigations the following formulas are given, together with Figs. 10 and 11. The curves in Fig. 10 have been calculated for a train composed of eight 40-ton cars while those of Fig. 11 have been calculated for a train of ten 60-ton cars.

Armstrong* $$R=\frac{50}{\cancel{W}}+0.035S+\frac{0.002\,a\,S^2}{W}\left[1+\frac{n-1}{10}\right]$$

$\sqrt{W}$

Blood† $$R=3+0.12S+\left[0.0014+\frac{0.40}{W}\right]S^{1.8}$$

*"Standard Handbook for Electrical Engineers," Section 13, p. 947, 1910.

†Proc. Amer. Soc. Mech. Eng., Vol. 24, p. 945, 1903.

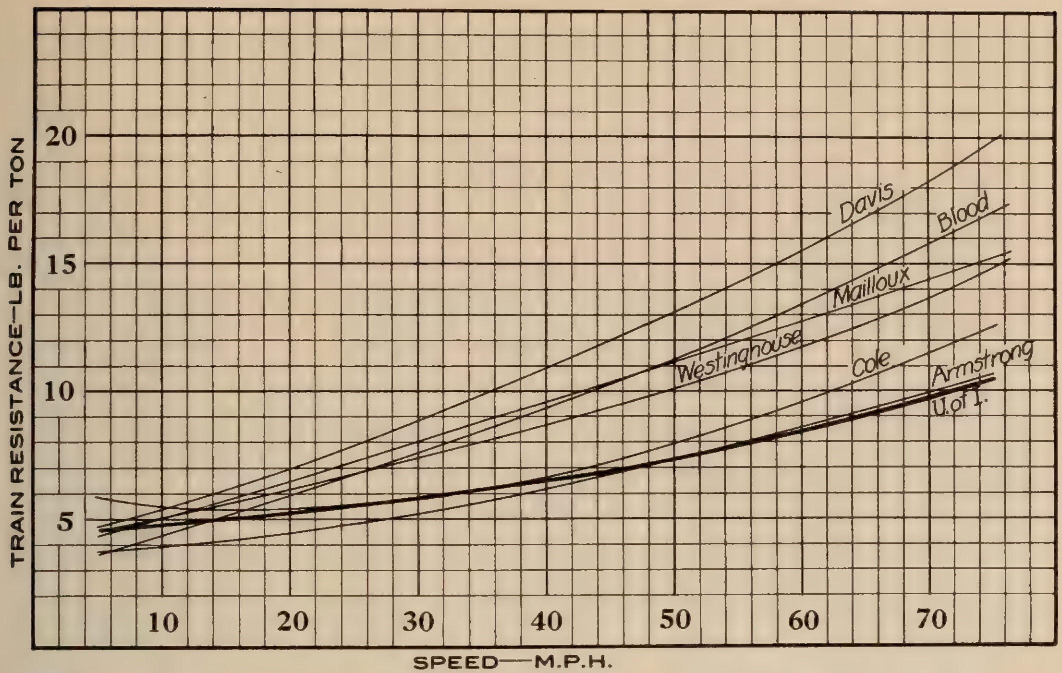

FIG. 11. COMPARATIVE CURVES SHOWING THE RELATION BETWEEN TRAIN RESISTANCE AND SPEED FOR TRAIN COMPOSED OF TEN 60-TON CARS

Cole* $$R = 5.4 + 0.002\,[S-15]^2 + \frac{100}{[S+2]^3}$$

Davis† $$R = 4 + 0.13\,S + \frac{0.33S^2}{W}\left[1 + \frac{n-1}{10}\right]$$

Mailloux‡ $$R = 3.5 + 0.15\,S + \left[\frac{(0.02\,N + 0.25)}{NW}\right]S^2$$

Westinghouse¶ $$R = 4 + \frac{S}{10} + \frac{10\,S^2}{36\,W}$$

Notation: R = train resistance, pounds per ton.
S = speed, miles per hour.
W = weight of the train, tons.
N = number of cars in the train.
A = cross sectional area.

*Railway Age Gazette, Vol. 47 n. s., pp. 361, 411, 451, 503, 546, 583, 1909.
†Street Railway Journal, Vol. 24, p. 1003, 1904.
‡Proc. Amer. Inst. Elec. Eng., Vol. 23, p. 731, 1904.
¶Westinghouse Company.

APPENDIX

Typical Tables of Results of the Individual Tests

In this appendix three tables are given, each of which shows the principal results of the calculations for one test. The tests have been chosen so that each one is fairly representative of all the tests made with a particular class of train. Table 4, for example, is typical of the results obtained with train No. 24, Table 5 representative of the tests with train No. 5, and Table 6 representative of the tests with train No. 2. The final values of net resistance on tangent, level track, at uniform speed are given in column 12, and the corresponding values of speed in column 11. These two columns give the coördinates of the points plotted on the individual diagrams of Figs. 1 to 5, inclusive.

It has been customary in bulletins of the Engineering Experiment Station of this nature to present complete tables of data for all the tests. This practice has been maintained largely for the purpose of showing the range of conditions such as wind velocity and direction, acceleration, grade and length of sections. It has also served to show the division of the gross train resistance into such items as acceleration, grade, and net resistance. In view of the fact that these data have been given so fully in previous publications and since the relation between the various items is not materially different in this case, it is thought that the presentation of typical tables of data is sufficient.

TABLE 4

THE RESULTS OF TEST NO. 7

Method of Calculation	Item No.	Length of Section Feet	Total Drawbar Pull Pounds	Acceleration Miles per Hour per Second	Speeds: At Entrance to Section m. p. h.	Speeds: At Exit from Section m. p. h.	Grade + Up — Down Feet per Mile	Wind: Approximate Direction	Wind: Approximate Velocity m. p. h.	Speed m. p. h.	Net Train Resistance Pounds per Ton
1	2	3	4	5	6	7	8	9	10	11	12
Section	1	1380	7060	....	00.00	24.05	— 1.15	+60° R	16	15.7	9.13
"	2	2700	4650	....	24.05	35.45	— 4.30	+60° R	16	30.7	9.10
"	3	3564	3510	....	35.45	43.90	— 9.90	+60° R	16	40.6	9.52
"	4	4112	2975	....	43.90	48.00	— 2.80	+60° R	16	46.7	10.68
"	5	4744	2675	....	48.00	51.55	— 3.90	+60° R	16	49.8	10.66
"	6	1008	6520	....	18.50	25.50	+11.00	+50° R	12	22.9	9.56
"	7	2800	4925	....	25.50	35.90	+ 4.30	+50° R	12	31.8	8.92
"	8	3532	3925	....	35.90	42.90	+ 0.70	+50° R	12	40.2	9.93
"	9	4160	2900	....	42.90	48.32	— 4.70	+50° R	12	47.3	9.07
"	10	4260	2275	....	48.32	48.00	+10.00	+50° R	12	48.4	8.97
"	11	2144	4650	....	17.60	29.25	— 3.40	+60° R	12	24.4	8.53
"	12	3024	3580	....	29.25	37.70	— 7.70	+60° R	12	34.4	9.12
"	13	3628	2825	....	37.70	43.25	— 8.30	+60° R	12	41.2	9.68
"	14	2036	4790	....	15.75	28.05	— 2.30	+35° R	10	23.2	8.12
"	15	2840	3540	....	28.05	34.45	+ 3.00	+35° R	10	32.3	8.07
"	16	3204	2860	....	34.45	37.40	+ 5.90	+35° R	10	36.4	8.53
"	17	2524	4960	....	21.80	33.25	+ 1.30	+40° R	10	28.7	8.78
"	18	3368	3850	....	33.25	40.92	— 0.60	+40° R	10	38.3	9.17
"	19	2240	5475	....	17.65	30.25	+ 6.60	+25° R	9	25.5	8.15
"	20	3052	4165	....	30.25	37.20	+ 7.60	+27° R	9	34.7	8.71
"	21	1948	4830	....	14.40	27.25	— 0.80	+60° R	10	22.1	7.07
"	22	2760	3540	....	27.25	33.60	+ 1.90	+60° R	10	31.4	8.56
"	23	3196	3050	....	33.60	37.40	+ 7.60	+60° R	10	35.3	7.63
"	24	3448	2710	....	37.40	40.10	+ 4.00	+60° R	10	39.2	8.83
"	25	3796	2325	....	41.95	43.25	+ 5.30	+60° R	10	43.1	8.47
"	26	1984	5020	....	15.85	26.55	+ 9.00	+45° R	8	22.6	7.63
"	27	2676	3925	....	26.55	32.95	+ 9.50	+45° R	8	30.4	7.55
"	28	3820	2425	....	40.95	44.40	— 2.50	+50° R	10	43.4	8.61
"	29	3664	2250	....	44.40	46.25	— 0.90	+50° R	10	45.5	9.25
"	30	4292	1950	....	46.25	49.00	— 8.90	+50° R	10	48.9	9.59
"	31	2084	4830	....	15.85	28.40	0.00	+25° R	7	23.7	7.37

TABLE 5

THE RESULTS OF TEST NO. 24

Method of Calculation	Item No.	Length of Section Feet	Total Drawbar Pull Pounds	Acceleration Miles per Hour per Second	Speeds: At Entrance to Section m. p. h.	Speeds: At Exit from Section m. p. h.	Grade + Up — Down Feet per Mile	Wind: Approximate Direction	Wind: Approximate Velocity m. p. h.	Speed m. p. h.	Net Train Resistance Pounds per Ton
1	2	3	4	5	6	7	8	9	10	11	12
Point	3	....	10630	+.1528	.....	.....	— 1.32	+15° L	3	16.20	4.50
"	4	....	18030	+.2745	.....	.....	+ 0.79	+40° R	6	11.00	5.15
"	5	....	13750	+.2185	.....	.....	— 7.04	+40° R	6	22.30	5.91
"	6	....	8600	+.1330	.....	.....	— 7.74	+40° R	6	30.40	5.36
Section	1	4484	5400	....	50.45	51.90	+ 2.51	+ 0°	8	50.90	6.20
"	2	5200	6150	....	49.00	53.40	— 6.10	+10° R	18	50.60	6.96
"	3	2968	4840	....	57.50	58.65	— 9.18	+10° R	24	57.80	8.79
"	4	4812	4000	....	60.20	60.80	— 5.01	+ 5° R	24	59.60	7.86
"	5	1788	500	....	61.70	61.70	—14.60	+ 5° R	23	61.30	6.42
"	6	3676	5700	....	49.90	51.30	+ 1.48	+10° R	22	50.10	6.74
"	7	3676	5600	....	51.15	51.00	+10.46	+10° R	22	50.10	6.15
"	8	3964	6480	....	54.75	54.75	+ 7.37	+10° R	20	54.00	8.56
"	9	4016	7300	....	45.35	47.10	+ 9.67	+20° R	18	45.60	6.33
"	10	4120	6890	....	50.80	52.80	+ 2.27	+20° R	20	51.00	7.67
"	38	1560	5000	....	52.40	52.80	— 0.74	+ 0°	8	53.20	9.68
"	39	2084	7150	....	46.40	48.85	— 4.33	+10° R	18	47.40	6.47
"	40	1976	5250	....	55.10	55.30	— 0.83	+15° R	22	53.90	6.73
"	41	2180	2400	....	60.50	60.50	—10.12	+ 5° R	24	59.40	8.04
"	42	1788	2100	....	60.80	61.40	—21.84	+ 5° R	23	61.00	8.94
"	43	2412	600	....	40.45	42.40	+ 0.57	+10° R	17	41.10	5.48
"	44	2028	8400	....	38.65	41.10	+ 6.04	+15° R	31	34.50	5.67
"	45	2972	6740	....	51.30	50.80	+15.47	+20° R	20	50.70	7.23
"	46	1816	7040	....	50.80	50.60	+14.85	+20° R	20	49.50	7.27
"	47	2944	4970	....	57.70	58.15	+ 2.74	+20° R	20	57.40	7.68

TABLE 6

THE RESULTS OF TEST NO. 19

Method of Calculation	Item No.	Length of Section Feet	Total Drawbar Pull Pounds	Acceleration Miles per Hour per Second	Speeds: At Entrance to Section m. p. h.	Speeds: At Exit from Section m. p. h.	Grade + Up — Down Feet per Mile	Wind: Approximate Direction	Wind: Approximate Velocity m. p. h.	Speed m. p. h.	Net Train Resistance Pounds per Ton
1	2	3	4	5	6	7	8	9	10	11	12
Point	1	....	15800	+.1610	.....	.....	+12.66	+15° R	13	22.40	4.78
"	2	....	15180	+.1920	.....	.....	0.00	....	..	24.40	5.40
"	3	....	12150	+.1626	.....	.....	— 7.92	+65° R	12	30.60	6.78
"	4	....	12850	+.1832	.....	.....	— 7.92	+45° R	5	27.00	5.94
"	8	....	16330	+.2258	.....	.....	— 2.64	+85° R	29	20.50	5.46
Section	1	820	6310	....	55.60	55.60	0.00	+25° R	24	55.90	9.92
"	2	1444	10510	....	36.20	37.85	+13.08	+25° R	19	39.40	5.68
"	3	1224	13250	....	29.40	32.30	+12.05	+30° R	14	33.20	6.12
"	4	3640	8500	....	46.90	49.00	+ 5.28	+25° R	24	49.65	7.53
"	5	1556	9850	....	40.00	41.95	+ 5.36	+30° R	19	42.49	6.35
"	6	3772	9900	....	35.40	40.00	+ 5.18	+30° R	19	39.60	7.25
"	7	1336	10380	....	33.00	35.40	+ 5.38	+30° R	19	36.40	5.90
"	8	3808	7700	....	49.60	49.80	+ 9.90	+30° R	24	51.90	8.01
"	9	3772	7380	....	49.00	49.60	+ 5.51	+25° R	20	51.45	8.43
"	10	2800	8180	....	45.60	46.60	+ 8.54	+30° R	22	47.72	7.35
"	11	5152	8380	....	45.60	44.40	+19.80	+30° R	21	46.85	7.18
"	12	1572	9500	....	40.30	42.00	0.00	+25° R	21	42.93	8.78
"	13	1256	12500	....	30.10	33.60	0.00	+15° R	13	34.20	7.43
"	14	5248	6250	....	57.70	58.40	0.00	+30° R	23	59.50	8.78
"	15	6016	6620	....	55.90	57.70	0.00	+30° R	23	58.60	8.07
"	16	5900	6940	....	55.30	55.70	+ 3.58	+40° R	20	57.30	9.06
"	17	4148	7150	....	53.80	55.30	0.00	+40° R	20	56.40	8.94
"	18	4296	7800	....	49.70	53.40	—10.00	—70° R	19	53.30	9.87
"	19	3228	8720	....	44.90	49.40	—10.01	—70° R	19	48.90	8.42
"	20	1316	9600	....	40.90	43.60	—10.02	+65° R	12	44.90	6.89
"	21	1420	10920	....	34.80	38.30	— 7.92	+65° R	12	38.75	7.73
"	22	2840	6300	....	53.00	54.10	— 3.24	+65° R	17	55.30	8.30
"	23	2400	6940	....	51.70	53.00	— 7.96	+65° R	17	54.50	10.02
"	24	4364	6880	....	53.00	51.00	+16.00	+40° R	21	54.15	8.06
"	25	2828	6800	....	53.20	53.20	0.00	....	..	55.10	10.73
"	26	3856	7180	....	50.60	50.20	+ 5.50	+60° R	21	52.40	9.98
"	27	2440	8150	....	45.00	46.60	0.00	+80° R	20	47.50	8.68
"	28	3256	8330	....	41.10	44.40	— 4.93	+70° R	15	44.40	9.02
"	29	1748	9400	....	36.40	39.80	—10.02	+70° R	15	39.75	8.38
"	30	2132	11950	....	27.10	33.80	— 3.61	+65° R	12	32.30	7.01

LIST OF
PUBLICATIONS OF THE ENGINEERING EXPERIMENT STATION

Bulletin No. 1. Tests of Reinforced Concrete Beams, by Arthur N. Talbot. 1904. *None available.*

Circular No. 1. High-Speed Tool Steels, by L. P. Breckenridge. 1905. *None available.*

Bulletin No. 2. Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 1905. *None available.*

Circular No. 2. Drainage of Earth Roads, by Ira O. Baker. 1906. *None available.*

Circular No. 3. Fuel Tests with Illinois Coal (Compiled from tests made by the Technological Branch of the U. S. G. S., at the St. Louis, Mo., Fuel Testing Plant, 1904–1907), by L. P. Breckenridge and Paul Diserens. 1908. *Thirty cents.*

Bulletin No. 3. The Engineering Experiment Station of the University of Illinois, by L. P. Breckenridge. 1906. *None available.*

Bulletin No. 4. Tests of Reinforced Concrete Beams, Series of 1905, by Arthur N. Talbot. 1906. *Forty-five cents.*

Bulletin No. 5. Resistance of Tubes to Collapse, by Albert P. Carman and M. L. Carr. 1906. *None available.*

Bulletin No. 6. Holding Power of Railroad Spikes, by Roy I. Webber. 1906. *None available.*

Bulletin No. 7. Fuel Tests with Illinois Coals, by L. P. Breckenridge, S. W. Parr, and Henry B. Dirks. 1906. *None available.*

Bulletin No. 8. Tests of Concrete: I, Shear; II, Bond, by Arthur N. Talbot. 1906. *None available.*

Bulletin No. 9. An Extension of the Dewey Decimal System of Classification Applied to the Engineering Industries, by L. P. Breckenridge and G. A. Goodenough. 1906. Revised Edition 1912. *Fifty cents.*

Bulletin No. 10. Tests of Concrete and Reinforced Concrete Columns, Series of 1906, by Arthur N. Talbot. 1907. *None available.*

Bulletin No. 11. The Effect of Scale on the Transmission of Heat through Locomotive Boiler Tubes, by Edward C. Schmidt and John M. Snodgrass. 1907. *None available.*

Bulletin No. 12. Tests of Reinforced Concrete T-Beams, Series of 1906, by Arthur N. Talbot. 1907. *None available.*

Bulletin No. 13. An Extension of the Dewey Decimal System of Classification Applied to Architecture and Building, by N. Clifford Ricker. 1907. *None available.*

Bulletin No. 14. Tests of Reinforced Concrete Beams, Series of 1906, by Arthur N. Talbot. 1907. *None available.*

Bulletin No. 15. How to Burn Illinois Coal without Smoke, by L. P. Breckenridge. 1908. *None available.*

Bulletin No. 16. A Study of Roof Trusses, by N. Clifford Ricker. 1908. *None available.*

Bulletin No. 17. The Weathering of Coal, by S. W. Parr, N. D. Hamilton, and W. F. Wheeler. 1908. *None available.*

Bulletin No. 18. The Strength of Chain Links, by G. A. Goodenough and L. E. Moore. 1908. *Forty cents.*

Bulletin No. 19. Comparative Tests of Carbon, Metallized Carbon and Tantalum Filament Lamps, by T. H. Amrine. 1908. *None available.*

Bulletin No. 20. Tests of Concrete and Reinforced Concrete Columns, Series of 1907, by Arthur N. Talbot. 1908. *None available.*

Bulletin No. 21. Tests of a Liquid Air Plant, by C. S. Hudson and C. M. Garland. 1908. *Fifteen cents.*

Bulletin No. 22. Tests of Cast-Iron and Reinforced Concrete Culvert Pipe, by Arthur N. Talbot 1908. *None available.*

Bulletin No. 23. Voids, Settlement and Weight of Crushed Stone, by Ira O. Baker. 1908. *Fifteen cents.*

**Bulletin No. 24.* The Modification of Illinois Coal by Low Temperature Distillation, by S. W. Parr and C. K. Francis. 1908. *Thirty cents.*

Bulletin No. 25. Lighting Country Homes by Private Electric Plants, by T. H. Amrine. 1908 *Twenty cents.*

*A limited number of copies of bulletins starred is available for free distribution.

Bulletin No. 26. High Steam-Pressure in Locomotive Service. A Review of a Report to the Carnegie Institution of Washington, by W. F. M. Goss. 1908. *Twenty-five cents.*

Bulletin No. 27. Tests of Brick Columns and Terra Cotta Block Columns, by Arthur N. Talbot and Duff A. Abrams. 1909. *Twenty-five cents.*

Bulletin No. 28. A Test of Three Large Reinforced Concrete Beams, by Arthur N. Talbot. 1909. *Fifteen cents.*

Bulletin No. 29. Tests of Reinforced Concrete Beams: Resistance to Web Stresses, Series of 1907 and 1908, by Arthur N. Talbot. 1909. *Forty-five cents.*

**Bulletin No. 30*. On the Rate of Formation of Carbon Monoxide in Gas Producers, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1909. *Twenty-five cents.*

**Bulletin No. 31*. Tests with House-Heating Boilers, by J. M. Snodgrass. 1909. *Fifty-five cents.*

Bulletin No. 32. The Occluded Gases in Coal, by S. W. Parr and Perry Barker. 1909. *Fifteen cents.*

Bulletin No. 33. Tests of Tungsten Lamps, by T. H. Amrine and A. Guell. 1909. *Twenty cents.*

**Bulletin No. 34*. Tests of Two Types of Tile-Roof Furnaces under a Water-Tube Boiler, by J. M Snodgrass. 1909. *Fifteen cents.*

Bulletin No. 35. A Study of Base and Bearing Plates for Columns and Beams, by N. Clifford Ricker. 1909. *Twenty cents.*

Bulletin No. 36. The Thermal Conductivity of Fire-Clay at High Temperatures, by J. K. Clement and W. L. Egy. 1909. *Twenty cents.*

Bulletin No. 37. Unit Coal and the Composition of Coal Ash, by S. W. Parr and W. F. Wheeler 1909. *None available.*

**Bulletin No. 38*. The Weathering of Coal, by S. W. Parr and W. F. Wheeler. 1909. *Twenty five cents.*

**Bulletin No. 39*. Tests of Washed Grades of Illinois Coal, by C. S. McGovney. 1909. *Seventy-five cents.*

Bulletin No. 40. A Study in Heat Transmission, by J. K. Clement and C. M. Garland. 1910. *Ten cents.*

Bulletin No. 41. Tests of Timber Beams, by Arthur N. Talbot. 1910. *Thirty-five cents.*

**Bulletin No. 42*. The Effect of Keyways on the Strength of Shafts, by Herbert F. Moore. 1910. *Ten cents.*

Bulletin No. 43. Freight Train Resistance, by Edward C. Schmidt. 1910. *Seventy-five cents*

Bulletin No. 44. An Investigation of Built-up Columns Under Load, by Arthur N. Talbot and Herbert F. Moore. 1911. *Thirty-five cents.*

**Bulletin No. 45*. The Strength of Oxyacetylene Welds in Steel, by Herbert L. Whittemore. 1911. *Thirty-five cents.*

**Bulletin No. 46*. The Spontaneous Combustion of Coal, by S. W. Parr and F. W. Kressman. 1911. *Forty-five cents.*

**Bulletin No. 47*. Magnetic Properties of Heusler Alloys, by Edward B. Stephenson, 1911. *Twenty-five cents.*

**Bulletin No. 48*. Resistance to Flow Through Locomotive Water Columns, by Arthur N. Talbot and Melvin L. Enger. 1911. *Forty cents.*

**Bulletin No. 49*. Tests of Nickel-Steel Riveted Joints, by Arthur N. Talbot and Herbert F. Moore. 1911. *Thirty cents.*

**Bulletin No. 50*. Tests of a Suction Gas Producer, by C. M. Garland and A. P. Kratz. 1912. *Fifty cents.*

Bulletin No. 51. Street Lighting, by J. M. Bryant and H. G. Hake. 1912. *Thirty-five cents.*

**Bulletin No. 52*. An Investigation of the Strength of Rolled Zinc, by Herbert F. Moore. 1912. *Fifteen cents.*

**Bulletin No. 53*. Inductance of Coils, by Morgan Brooks and H. M. Turner. 1912. *Forty cents.*

**Bulletin No. 54*. Mechanical Stresses in Transmission Lines, by A. Guell. 1912. *Twenty cents.*

**Bulletin No. 55*. Starting Currents of Transformers, with Special Reference to Transformers with Silicon Steel Cores, by Trygve D. Yensen. 1912. *Twenty cents.*

**Bulletin No. 56*. Tests of Columns: An Investigation of the Value of Concrete as Reinforcement for Structural Steel Columns, by Arthur N. Talbot and Arthur R. Lord. 1912. *Twenty-five cents*

**Bulletin No. 57*. Superheated Steam in Locomotive Service. A Review of Publication No. 127 of the Carnegie Institution of Washington, by W. F. M. Goss. 1912. *Forty cents.*

*A limited number of copies of bulletins starred is available for free distribution.

**Bulletin No. 58.* A New Analysis of the Cylinder Performance of Reciprocating Engines, by J. Paul Clayton. 1912. *Sixty cents.*

**Bulletin No. 59.* The Effect of Cold Weather upon Train Resistance and Tonnage Rating, by Edward C. Schmidt and F. W. Marquis. 1912. *Twenty cents.*

Bulletin No. 60. The Coking of Coal at Low Temperatures, with a Preliminary Study of the By-Products, by S. W. Parr and H. L. Olin. 1912. *Twenty-five cents.*

**Bulletin No. 61.* Characteristics and Limitation of the Series Transformer, by A. R. Anderson and H. R. Woodrow. 1913. *Twenty-five cents.*

Bulletin No. 62. The Electron Theory of Magnetism, by Elmer H. Williams. 1913. *Thirty-five cents.*

Bulletin No. 63. Entropy-Temperature and Transmission Diagrams for Air, by C. R. Richards. 1913. *Twenty-five cents.*

**Bulletin No. 64.* Tests of Reinforced Concrete Buildings under Load, by Arthur N. Talbot and Willis A. Slater. 1913. *Fifty cents.*

**Bulletin No. 65.* The Steam Consumption of Locomotive Engines from the Indicator Diagrams, by J. Paul Clayton. 1913. *Forty cents.*

Bulletin No. 66. The Properties of Saturated and Superheated Ammonia Vapor, by G. A. Goodenough and William Earl Mosher. 1913. *Fifty cents.*

Bulletin No. 67. Reinforced Concrete Wall Footings and Column Footings, by Arthur N. Talbot. 1913. *Fifty cents.*

Bulletin No. 68. The Strength of I-Beams in Flexure, by Herbert F. Moore. 1913. *Twenty cents.*

Bulletin No. 69. Coal Washing in Illinois, by F. C. Lincoln. 1913. *Fifty cents.*

Bulletin No. 70. The Mortar-Making Qualities of Illinois Sands, by C. C. Wiley. 1913. *Twenty cents.*

Bulletin No. 71. Tests of Bond between Concrete and Steel, by Duff A. Abrams. 1914. *One dollar.*

**Bulletin No. 72.* Magnetic and Other Properties of Electrolytic Iron Melted in Vacuo, by Trygve D. Yensen. 1914. *Forty cents.*

Bulletin No. 73. Acoustics of Auditoriums, by F. R. Watson. 1914. *Twenty cents.*

**Bulletin No. 74.* The Tractive Resistance of a 28-Ton Electric Car, by Harold H. Dunn. 1914. *Twenty-five cents.*

Bulletin No. 75. Thermal Properties of Steam, by G. A. Goodenough. 1914. *Thirty-five cents.*

Bulletin No. 76. The Analysis of Coal with Phenol as a Solvent, by S. W. Parr and H. F. Hadley. 1914. *Twenty-five cents.*

**Bulletin No. 77.* The Effect of Boron upon the Magnetic and Other Properties of Electrolytic Iron Melted in Vacuo, by Trygve D. Yensen. 1915. *Ten cents.*

**Bulletin No. 78.* A Study of Boiler Losses, by A. P. Kratz. 1915. *Thirty-five cents.*

**Bulletin No. 79.* The Coking of Coal at Low Temperatures, with Special Reference to the Properties and Composition of the Products, by S. W. Parr and H. L. Olin. 1915. *Twenty-five cents.*

Bulletin No. 80. Wind Stresses in the Steel Frames of Office Buildings, by W. M. Wilson and G. A. Maney. 1915. *Fifty cents.*

**Bulletin No. 81.* Influence of Temperature on the Strength of Concrete, by A. B. McDaniel. 1915. *Fifteen cents.*

Bulletin No. 82. Laboratory Tests of a Consolidation Locomotive, by E. C. Schmidt, J. M. Snodgrass, and R. B. Keller. 1915. *Sixty-five cents.*

**Bulletin No. 83.* Magnetic and Other Properties of Iron Silicon Alloys, Melted in Vacuo, by Trygve D. Yensen. 1915. *Thirty-five cents.*

Bulletin No. 84. Tests of Reinforced Concrete Flat Slab Structures, by Arthur N. Talbot and W. A. Slater. 1916. *Sixty-five cents.*

**Bulletin No. 85.* The Strength and Stiffness of Steel under Biaxial Loading, by A. T. Becker. 1916. *Thirty-five cents.*

**Bulletin No. 86.* The Strength of I-Beams and Girders, by Herbert F. Moore and W. M. Wilson. 1916. *Thirty cents.*

**Bulletin No. 87.* Correction of Echoes in the Auditorium, University of Illinois, by F. R. Watson and J. M. White. 1916. *Fifteen cents.*

Bulletin No. 88. Dry Preparation of Bituminous Coal at Illinois Mines, by E. A. Holbrook. 1916. *Seventy cents.*

---

*A limited number of copies of bulletins starred is available for free distribution.

**Bulletin No. 89.* Specific Gravity Studies of Illinois Coal, by Merle L. Nebel. 1916. *Thirty cents.*

**Bulletin No. 90.* Some Graphical Solutions of Electric Railway Problems, by A. M. Buck. 1916. *Twenty cents.*

Bulletin No. 91. Subsidence Resulting from Mining, by L. E. Young and H. H. Stoek. 1916. *None available.*

**Bulletin No. 92.* The Tractive Resistance on Curves of a 28-Ton Electric Car, by E. C. Schmidt and H. H. Dunn. 1916. *Twenty-five cents.*

**Bulletin No. 93.* A Preliminary Study of the Alloys of Chromium, Copper, and Nickel, by D. F. McFarland and O. E. Harder. 1916. *Thirty cents.*

**Bulletin No. 94.* The Embrittling Action of Sodium Hydroxide on Soft Steel, by S. W. Parr. 1917. *Thirty cents.*

**Bulletin No. 95.* Magnetic and Other Properties of Iron-Aluminum Alloys Melted in Vacuo, by T. D. Yensen and W. A. Gatward. 1917. *Twenty-five cents.*

**Bulletin No. 96.* The Effect of Mouthpieces on the Flow of Water through a Submerged Short Pipe, by Fred B Seely, 1917. *Twenty-five cents.*

**Bulletin No. 97.* Effects of Storage upon the Properties of Coal, by S. W. Parr. 1917. *Twenty cents.*

**Bulletin No. 98.* Tests of Oxyacetylene Welded Joints in Steel Plates, by Herbert F. Moore. 1917. *Ten cents.*

Circular No. 4. The Economical Purchase and Use of Coal for Heating Homes, with Special Reference to Conditions in Illinois. 1917. *Ten cents.*

**Bulletin No. 99.* The Collapse of Short Thin Tubes, by A. P. Carman. 1917. *Twenty cents.*

**Circular No. 5.* The Utilization of Pyrite Occurring in Illinois Bituminous Coal, by E. A. Holbrook. 1917. *Twenty cents.*

**Bulletin No. 100.* Percentage of Extraction of Bituminous Coal with Special Reference to Illinois Conditions, by C. M. Young. 1917.

**Bulletin No. 101.* Comparative Tests of Six Sizes of Illinois Coal on a Mikado Locomotive, by E. C. Schmidt, J. M. Snodgrass, and O. S. Beyer, Jr. 1917. *Fifty cents.*

**Bulletin No. 102.* A Study of the Heat Transmission of Building Materials, by A. C. Willard and L. C. Lichty. 1917. *Twenty-five cents.*

**Bulletin No. 103.* An Investigation of Twist Drills, by B. Benedict and W. P. Lukens. 1917. *Sixty cents.*

**Bulletin No. 104.* Tests to Determine the Rigidity of Riveted Joints of Steel Structures by W. M. Wilson and H. F. Moore. 1917. *Twenty-five cents.*

Circular No. 6. The Storage of Bituminous Coal, by H. H. Stoek. 1918. *Forty cents.*

Circular No. 7. Fuel Economy in the Operation of Hand Fired Power Plants. 1918. *Twenty cents.*

**Bulletin No. 105.* Hydraulic Experiments with Valves, Orifices, Hose, Nozzles, and Orifice Buckets, by Arthur N. Talbot, Fred B Seely, Virgil R. Fleming and Melvin L. Enger. 1918. *Thirty-five cents.*

**Bulletin No. 106.* Test of a Flat Slab Floor of the Western Newspaper Union Building, by Arthur N. Talbot and Harrison F. Gonnerman. 1918. *Twenty cents.*

Circular No. 8. The Economical Use of Coal in Railway Locomotives. 1918. *Twenty cents.*

**Bulletin No. 107.* Analysis and Tests of Rigidly Connected Reinforced Concrete Frames, by Mikishi Abe. 1918. *Fifty cents.*

**Bulletin No. 108* Analysis of Statically Indeterminate Structures by the Slope Deflection Method, by W. M. Wilson, F. E. Richart and Camillo Weiss. 1918. *One dollar.*

**Bulletin No. 109.* The Pipe Orifice as a Means of Measuring Flow of Water through a Pipe, by H. H. Jordan and R. E. Davis. 1918.

**Bulletin No. 110.* Passenger Train Resistance, by E. C. Schmidt and H. H. Dunn. 1918. *Twenty cents.*

---

*A limited number of copies of bulletins starred is available for free distribution.

THE UNIVERSITY OF ILLINOIS

THE STATE UNIVERSITY

Urbana

EDMUND J. JAMES, Ph.D., LL.D., President

THE UNIVERSITY INCLUDES THE FOLLOWING DEPARTMENTS:

The Graduate School

The College of Liberal Arts and Sciences (Ancient and Modern Languages and Literatures; History, Economics, Political Science, Sociology; Philosophy, Psychology, Education; Mathematics; Astronomy; Geology; Physics; Chemistry; Botany, Zoology, Entomology; Physiology; Art and Design)

The College of Commerce and Business Administration (General Business, Banking, Insurance, Accountancy, Railway Administration, Foreign Commerce; Courses for Commercial Teachers and Commercial and Civic Secretaries)

The College of Engineering (Architecture; Architectural, Ceramic, Civil, Electrical, Mechanical, Mining, Municipal and Sanitary, and Railway Engineering)

The College of Agriculture (Agronomy; Animal Husbandry; Dairy Husbandry; Horticulture and Landscape Gardening; Agricultural Extension; Teachers' Course; Household Science)

The College of Law (three years' course)

The School of Education

The Course in Journalism

The Courses in Chemistry and Chemical Engineering

The School of Railway Engineering and Administration

The School of Music (four years' course)

The School of Library Science (two years' course)

The College of Medicine (in Chicago)

The College of Dentistry (in Chicago)

The School of Pharmacy (in Chicago; Ph. G. and Ph. C. courses)

The Summer Session (eight weeks)

Experiment Stations and Scientific Bureaus: U. S. Agricultural Experiment Station; Engineering Experiment Station; State Laboratory of Natural History; State Entomologist's Office; Biological Experiment Station on Illinois River; State Water Survey; State Geological Survey; U. S. Bureau of Mines Experiment Station.

The library collections contain (November 1, 1918) 437,949 volumes and 108,289 pamphlets.

For catalogs and information address

THE REGISTRAR

URBANA, ILLINOIS